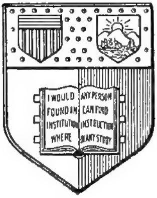
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MANUAL

OF

CATTLE-FEEDING.

A TREATISE ON

THE LAWS OF ANIMAL NUTRITION AND THE CHEMISTRY OF
FEEDING-STUFFS IN THEIR APPLICATION TO
THE FEEDING OF FARM-ANIMALS.

With Illustrations and an Appendix of Useful Tables.

By HENRY P. ARMSBY, Ph.D.,
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SECOND EDITION.

NEW YORK:
JOHN WILEY & SONS,
15 Astor Place.
1882.

uS
m.H.

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1880.

Trow's
Printing and Bookbinding Company,
201-213 *East 12th Street*,
NEW YORK.

PREFACE.

INVESTIGATION into the laws which form the basis of the rational feeding of live-stock has been most actively and industriously carried on of late years, and very important advances have been made, especially in Germany, where this branch of applied science has been most attentively and persistently studied. The period since the year 1860, in particular, has been a remarkably fruitful one; within this period the theory of feeding has been placed on a firm, scientific foundation, and the direction of its future progress has been marked out; and while very much still remains to be done, the results already achieved are of great practical importance.

Unfortunately, however, these results are largely inaccessible to the majority of American feeders, and those of them which appear from time to time in agricultural papers and other publications are deprived of much of their good effect by their necessarily fragmentary character.

It is the object of this work to present these results in a connected and systematic form to American farmers and others interested in stock-feeding, an attempt which, so far as the writer is aware, has not before been made, and a few words as to the scope and aims of such a book will therefore be in place.

In the writer's view, the highest usefulness of a work like the present does not consist simply in giving receipts which shall enable the farmer to feed his stock more economically, or to produce more milk or more or better beef, but in so elucidating our knowledge of the unchanging natural laws, chemical and physiological, of the nutrition of animals, that the attentive student shall be able to adapt his practice to the varying conditions in which he may be placed, and, more important still, shall be able to appropriate intelligently the results of new investigations and follow or take part in the advances of the science.

Guided by this idea, the author has not been content simply to state results, but has endeavored, so far as was possible in an elementary work, to indicate the processes by which these results have been reached and the degree of certainty which attaches to them, as well as to point out the directions in which our knowledge is still deficient. Only in this way can a correct idea of the present state of the science be obtained or the learner be prepared to appreciate and utilize further progress. In this the chiefly practical importance of the subject has not been forgotten.

The ultimate object of this branch of applied science is, of course, to enable us to feed better and more economically; but the only sure and lasting foundation for a rational practice is a knowledge of the natural laws on which it is based, and with which it must be in accordance in order to be successful.

This method of treating the subject naturally makes demands for study and thought on the part of the reader; the results of twenty years of arduous scientific work by scores of investigators are not to be grasped and appropriated without labor. At the same time the author has endeavored to reduce this labor as much as is possible without the sacrifice of accuracy and a reasonable degree of fulness. Above all, he has sought to make his work a reliable exponent of the present state of knowledge on the subject of cattle-feeding, and to draw a sharp line between proved and useful facts, and merely probable hypotheses or speculations.

This book was begun as a translation of Wolff's "*Landwirthschaftliche Fütterungslehre,*" a volume of some two hundred pages. It was soon found, however, that considerable additions and changes were required to suit it to American readers, and the work has finally assumed its present form. Some portions of it are still free translations of Wolff, but much more of it has been either added or entirely rewritten, and a number of illustrations have been introduced, so that the character of the book has been considerably altered. One of the most marked changes is the substitution, in the Appendix, of Kühn's tables of the composition and digestibility of feeding-stuffs for those of Wolff. Although the writer does not accept all of Kühn's opinions, he yet believes that tables arranged on the plan adopted by Kühn are, on the whole, preferable to those containing simply averages; and in view of the changes and additions made elsewhere in the volume, he has felt justified in making the substitution named, though aware that Kühn's views, on some points, are warmly opposed by Wolff.

In addition to the "*Fütterungslehre,*" the author is especially indebted to Wolff's larger book, "*Die Ernährung der landwirthschaftlichen Nutzthiere,*" while other works and the current literature of the subject have been freely consulted.

SEPT. 1, 1880.

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MANUAL OF CATTLE-FEEDING.

INTRODUCTION.

THE two objects of agriculture are the production of plants and of animals.

We must seek for the laws governing the former in the chemistry and physics of the air, the soil, and manures, and in the phenomena of vegetable growth; while a scientific study of the latter involves a consideration of the laws of animal nutrition and growth, and of the chemistry of plants, so far as they are used as food.

All forms of life with which we are acquainted, vegetable as well as animal, manifest themselves through the breaking up of more complex into simpler compounds, accompanied by a liberation of energy.

The broad distinction between vegetable and animal life is, that plants are able to appropriate the force which exists in the sun's rays and use it to build up these complex compounds out of very simple, so-called *inorganic* materials, while animals lack this power, and are obliged to avail themselves of the compounds already formed by plants.

In the economy of nature, the office of the plant is to store up energy from the sun's rays in certain complex compounds, setting free oxygen in the process; while the animal takes these compounds and utilizes the latent energy which they contain for his vital processes, the substances themselves uniting again with the oxygen from which they were separated in the plant. In the plant the spring is wound up—in the animal it unwinds and gives out just as much force as was used in winding it up. The two processes supplement each other; the whole is a complete circle.

A living animal, then, is constantly decomposing and oxidizing the materials of its own body. These first break up in the cells of the body, independently of oxygen, in accordance with the laws which regulate vital phenomena, and give out part of the latent energy which they contained. Then the oxygen of the air, carried by the blood to every part of the body, seizes on the resulting substances and burns them, more or less rapidly, producing a large quantity of heat to replace that which the body is constantly losing by radiation and otherwise, while the products of this burning are finally excreted from the body.

The body is thus continually suffering a loss of material. To replace this loss, as well as to supply material for further growth, is the office of the food, which may, from this point of view, be regarded as a vehicle for the introduction of supplies of force into the body.

It is the object of such a book as the present one to show how much and what kind of food is needed to supply the losses arising under the various conditions to which farm animals are subject. In order to do this intelligently, we need to consider: *first*, the nature and extent of the processes going on in the body; *second*, the materials available as food; and *third*, the adaptation of these materials to the various purposes of feeding. The subject, then, naturally divides itself into three parts:

I. The General Laws of Animal Nutrition, or that portion of animal physiology which treats of the so-called "vegetative functions." This includes the composition of the animal body, the processes of digestion, circulation and respiration, and the production of flesh, fat, and work.

II. The Composition and Digestibility of Feeding-Stuffs.

III. The Feeding of Farm Animals—a consideration of the kind and quantity of food required for the various purposes for which such animals are kept.

PART I.

THE GENERAL LAWS OF ANIMAL NUTRITION.

CHAPTER I.

THE COMPOSITION OF THE ANIMAL BODY.

§ 1. PROPORTIONS OF THE DIFFERENT ORGANS AND PARTS.

The Fluids circulating in the blood and lymph vessels constitute but a small part, at most not more than 7 to 9 per cent., of the live weight, and in old or very fat animals the proportion sinks as low as from 4 to 6 per cent. The digestive fluids and other secretions and fluid excretions, although they are produced in considerable quantity in the course of twenty-four hours, can hardly be taken into account as constituents of the body, since they are being produced at every instant, are formed more or less directly from the blood, and are partly re-absorbed into it or pass out of the body; while the blood, on the other hand, although continually giving up material to the tissues and receiving new from the food, remains very constant in its quantity and chemical properties.

The Solid Tissues.—The fresh bones constitute, according to the kind, age, and condition of the animal, 6 to 12 per cent. of its weight, the muscles and tendons 35 to 48 per cent., and the fat, so far as it can be mechanically separated, 10 to 40 per cent. It is to be noted, however, that the fresh bones contain 11 to 14 per cent. of water, and the muscles from 60 to over 75 per cent. The average of the results of numerous investigations made on the various farm animals gives them approximately the following composition:

Bones	9	per cent.
Flesh and tendons	40	"
Mechanically separable fat	24	"

The remaining 27 per cent. comprises the blood, hide and hair, entrails, and the contents of stomach and intestines. Fuller details regarding the proportions of the various parts in lean and fat animals of various kinds are to be found in the Appendix.

It should be added that the volume and weight of the contents of the stomach and intestines are very various, according to whether the animal has received a more or less bulky fodder. For example, in some investigations made by E. v. Wolff, in Hohenheim, with sheep, the following averages were obtained:

No. of Experiments.	Fodder.	Average live weight per head. Pounds.	Contents of stomach and intestines. Pounds.	Contents in per cent. of live weight.
3*	Chiefly straw	93.8	20.9	22.3
2*	Hay, with small amount of beans	100.1	16.0	15.9
6†	Clover hay, potatoes, peas, and corn	124.2	11.2	9.04

---

* "Die Versuchs-Station Hohenheim," 1866–1870, p. 62.

† Landw. Jahrbücher, I., 569.

Grouven[*] found in the case of oxen:

No. of Experiments.	Fodder.	Live weight. Pounds.	Contents of stomach and intestines. Pounds.	Contents in per cent. of live weight.
4	Straw..................	1,199	199	16.6
7	Fattening fodder.	1,419	133	9.4

Fatted hogs give a less proportion, viz., 4 to 6 per cent. Lawes and Gilbert[†], in fifty-nine experiments, found the proportion of stomach and intestines, together with their contents, to range from 5.59 per cent. to 10.13 per cent. of the live weight, the average being 7.52 per cent.

§ 2. THE NON-NITROGENOUS CONSTITUENTS OF THE ANIMAL BODY.

Water.—One of the most important constituents of the animal body is water.

This substance constitutes, under most circumstances, more than half of the entire weight of the animal; it is contained in all parts of the body, and forms as essential an ingredient of the so-called solid tissues as do any of their other components.

In the new-born animal, water constitutes 80 to 85 per cent. of the total weight, but during the period of rapid growth the proportion of dry matter increases and that of water diminishes, so that the mature, but not fattened, animal may contain 50 to 60 per cent. of water. In the process of fattening, the percentage of water decreases still more, falling, according to the experiments of Lawes and Gilbert, below 50 per cent., and in one case (a very fat sheep) to 35.2 per cent. of the whole animal, or 33 per cent. of the dressed carcass.

---

[*] Zweiter Salzmünde Bericht, 1864, p. 137, and Erster Bericht, 1862, p. 260.

[†] Jour. Roy. Ag. Soc., Series I., XXI., 449.

It is sometimes stated that, in fattening, the body loses water, its place being taken by nitrogenous matters and especially by fat, but the author has not been able to find any account of experiments which substantiate this view.

Fat animals, it is true, contain a smaller percentage of water and a larger percentage of fat than lean ones, but this is not sufficient to prove the point, for an increase in the *absolute* amount of fat contained in an animal would cause a decrease in the *relative* amount (percentage) of all the other ingredients, water included.

The only method by which the truth of the above view can be determined, is to compare the *absolute* weight of water, fat, albuminoids, etc., in lean and fat animals of the same breed and as nearly alike as possible.

Such comparisons have been made by Lawes and Gilbert,* in the following manner. Ten animals of different kinds, and in different stages of fatness, were slaughtered, and the percentages of ash, albuminoids, fat, and water in the whole animal determined, and by this means data were obtained for estimating the absolute amounts of these substances in the body of a living animal whose weight was known.

A large number of animals were then fattened, and, their composition before and after being estimated as above, it was easy to determine the amount of each ingredient which had been produced, and from this the percentage composition of the increase in weight.

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* Jour. Roy. Agr. Soc., Series I., XXI., 456.

The following table shows the average results for oxen, sheep, and hogs:

Average Composition of the Increase of Live Weight in Fattening.

	Ash. Per cent.	Protein. Per cent.	Fat. Per cent.	Total dry matter. Per cent.	Water. Per cent.
98 Oxen..............	1.47	7.69	66.2	75.4	24.6
348 Sheep.............	2.34 *	7.13	70.4	79.9	20.1
80 Hogs...............	0.06 †	6.44	71.5	78.0	22.0
Average............	1.10	7.26	67.8	76.2	23.8

It is evident from the method followed that the results are not absolutely accurate, but they suffice to show that in fattening, a *gain* of water takes place, though it is relatively small.

The same conclusion is indicated by recent experiments by Henneberg, Kern, and Wattenberg,‡ on the fattening of sheep.

They slaughtered animals in two stages of fattening, and also, at the beginning of the experiment, others which had not been fattened. The following numbers, taken from their results, show the total gain of weight by the "fat" and the "very fat" animals, and also the excess of fat and flesh contained in their bodies over that found in the unfatted ones:

---

* Probably too high, owing to dirt in the wool.

† Probably too low.

‡ Biedermann's Central-Blatt., Jahrg. 8, p. 262.

	Lean. Pounds.	Fat. Pounds.	Very fat. Pounds.
Original weight	90.53	89.54	89.10
Final weight	90.53	116.45	123.86
Gain	......	26.91	34.76
Gain of fat	......	24.51	33.78
Gain of flesh	......	—0.33	0.51
Total, fat and flesh	......	23.18	34.29

The increase of fat and flesh is, in each case, less than the total gain, showing that there was a gain of something else, and making it improbable that any essential loss of water took place, especially as the flesh was found to contain almost exactly the same percentage of water in the very fat and in the lean animals, viz.:

Lean	79.41 per cent.
Very fat	79.02 "

Unfortunately, however, no such complete analyses of the whole animal were made in these trials as in those of Lawes and Gilbert, and hence the data which they afford are insufficient to settle the question.

The dry substance of the animal body consists of organic and inorganic matter, and the former, again, of nitrogenous and non-nitrogenous materials.

By *organic* matter, in the above sense, is understood matter which is combustible, and which, when subjected to the action of fire, disappears, leaving the *inorganic* matter behind as ashes.

The terms are not strictly correct, since the ash of a piece of flesh, or of a mass of wood, was as really *organized*, and formed as truly a part of it, as the so-called *organic* portion, but they are in common use with this meaning. The organic matters of the animal body are classified, according to whether they contain the element nitrogen or not, as nitrogenous or non-nitrogenous.

Fat.—Of the non-nitrogenous substances fat is by far the most abundant. It is present in the blood in minute quantities, generally constituting not more than 0.1 to 0.3 per cent. of it; it exists in larger quantity in the substance of the nerves and in the bones, but is chiefly found enclosed in special cells or tissues under the skin, on the kidneys, omentum, and mesentery, and in the flesh between the bundles of muscular fibres.

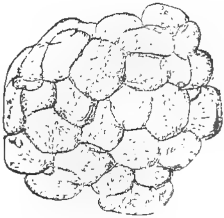
FIG. 1.—(Settegast). Fat-cells.

The thin membrane which composes the cell-walls of the fat-tissue is a nitrogenous substance, and constitutes only 0.8 per cent. of the whole tissue when the latter is entirely filled with fat, but when this is not the case its amount may rise to 4 per cent., or over.

The quantity of water in the fresh fat-tissue stands in a fixed relation to the amount of membrane (about 5 or 6 to 1), so that the quantity of water may vary from 4 to over 24 per cent., according to whether the cells are more or less laden with fat.

Most of the fat-cells of the living body contain liquid, perfectly transparent fat, but its consistency varies in the different organs; it solidifies to a solid, butter-like mass more or less easily, according to whether the oily or the solid fats predominate. The appearance, also, as well as the smell and taste, of fat taken from different kinds of animals, or from different parts of the same animal, is very variable, on account of admixtures of small quantities of coloring matters and volatile substances of all sorts; but this has almost no influence upon the elementary composition of the fat, which is very constant.

Schulze and Reinecke,* at the Weende Experiment Station, found twenty-eight samples of mutton, beef, and pork fat, taken from different individuals and from different parts of the body, and freed from the fat-membrane and from water, to have the following composition:

	No. of Samples.	Carbon.			Hydrogen.			Oxygen.		
		Av. Per cent.	Max. Per cent.	Min. Per cent.	Av. Per cent.	Max. Per cent.	Min. Per cent.	Av. Per cent.	Max. Per cent.	Min. Per cent.
Beef fat..........	10	76.50	76.74	76.27	11.91	12.11	11.76	11.59	11.86	11.15
Pork fat..........	6	76.54	76.78	76.29	11.94	12.07	11.86	11.52	11.83	11.15
Mutton fat........	12	76.61	76.85	76.27	12.03	12.16	11.87	11.36	11.56	11.00
Average of all the Analyses in round numbers.		76.50			12.00			11.50		

Other results were:

Fat from	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.
Dog..........	76.63	12.05	11.32
Cat..........	76.56	11.90	11.44
Horse........	77.07	11.69	11.24
Man..........	76.62	11.94	11.44

---

* Versuchs-Stationen, IX., 97.

It is evident from these figures that in all calculations regarding the gain or loss of fat by the body, we may treat this fat, in spite of the numerous modifications which it undergoes in the various organs, as chemically identical, without falling into any appreciable error.

The quantity of fat which may be laid up in the body is often enormous. For example, in the case of fattened neat-cattle and swine, the fat may make up from 25 to over 40 per cent. of the live weight of these animals, or from two to three times as much as all the nitrogenous substances present. In lean animals, on the other hand, the amount of fat is much less, and that of the nitrogenous substances relatively greater.

Other Non-Nitrogenous Organic Substances.—All the non-nitrogenous organic substances, other than fat, which occur in the body, and are to be regarded as normal constituents of it, are very inconsiderable in quantity, although often of importance for the functions of the organs or fluids in which they are found.

The gastric juice (the digestive fluid of the stomach), and also the contents of the large and small intestines, and sometimes the chyle of the thoracic duct (see p. 68), contain *lactic acid*, the well-known acid of sour milk, while the juices of the flesh contain another acid—*sarkolactic acid*—isomeric* with the former.

The blood, and in fact almost all the animal fluids, also contain minute quantities of one or the other of these acids.

Sugar is likewise found in the blood, but at most in quantities not exceeding 0.015 per cent., except in the blood of the hepatic vein (the vein leading from the liver toward the heart), where the amount rises to about 0.1 per cent.

---

* Two substances are said to be isomeric when they have the same percentage composition, but different chemical properties.

The liver itself contains a considerable quantity of a substance called *glycogen*, somewhat resembling starch, which is continually yielding sugar by its decomposition. The sugar in the hepatic vein has its source in the glycogen of the liver.

The muscles likewise contain glycogen, and also small quantities of a non-nitrogenous substance peculiar to themselves, and resembling sugar in composition and properties, called *inosite*.

Furthermore, various non-nitrogenous organic compounds occur in the bile, and innumerable such in the so-called extractive matters of the tissues and juices, that is in the mixture of substances obtained by treating the flesh, etc., with alcohol. The "extractive matters" give to meat soup its agreeable taste and smell. The weight of all these substances, however, is inconsiderable, and vanishes almost entirely in comparison with the great quantities of fat and nitrogenous matter in the whole body.

§ 3. NITROGENOUS ORGANIC SUBSTANCES.

Of the nitrogenous constituents of the body, there are three principal groups to be considered, viz., the ALBUMINOIDS, GELATIGENOUS SUBSTANCES, and HORNY MATTERS.

The albuminoids are by far the most important of the three, since all manifestations of animal life are dependent chiefly on them and the organs which are composed of them, and since they furnish the material out of which the members of both the other groups are formed; while the latter, once formed, do not appear to be capable of being altered back into albuminoids, or of performing the functions of the latter in nourishing the body.

ALBUMINOIDS.—The albuminoids are found in manifold modifications in all the organs and fluids of the healthy body, except the urine, and all these modifications suffer an almost continual mutual alteration under the influence of the vital processes.

Notwithstanding their diversity, however, they have many and marked characteristics in common.

As their name implies (albuminoid—albumin-like), they resemble albumin or white of egg. Like it, they are destitute of any crystalline form (amorphous). Most of them exist in at least two modifications—a soluble and an insoluble one. In the soluble form they constitute, when dried at a gentle heat, transparent, white or yellowish solids, destitute of taste or smell, and soluble in water; in the insoluble modification they form white, flocculent or fibrous masses, insoluble in water, and, like the soluble forms, having neither taste nor smell.

The soluble albuminoids are very readily converted into the insoluble form by a variety of means; in some cases by heat, in others by the action of acids or other bodies, and in still others from some cause not yet known. This change is called *coagulation;* it is apparently only a change in the condition and not in the nature of the substance. At any rate, it is not accompanied by any change in composition.

Almost innumerable varieties of albuminoids have been described, and much confusion exists as to their properties, and relations to each other. For our present purpose, however, it will suffice to indicate the three groups into which these bodies may be classified—viz.:

Albumin (represented by white of egg), *Fibrin* (represented by lean meat), and *Casein* (the basis of cheese).

Albumin predominates in all animal fluids, especially in the so-called chyle, in the colorless serum (see below) of the blood, and in the fluid contents of the blood-corpuscles, where it is tinted red by the coloring matter of the blood. It also occurs in the juice of the muscles and in the nerves.

It is distinguished by the property of coagulating when heated above a certain point. For pure albumin this point is 165° F.; for solutions of albumin it is higher in proportion as they are more dilute.

(A good example of coagulation is furnished in the boiling of an egg. As the heat of the boiling water penetrates the egg the albumin changes from a transparent soluble liquid to an opaque solid which no longer dissolves in water.)

Fibrin.—The blood of all the higher animals, shortly after it is removed from the body, partially solidifies, and separates into two parts, the "clot" and a yellowish liquid called the serum. The serum contains albumin and the dissolved matters of the blood generally; the clot contains an albuminoid known as *blood-fibrin*, colored red by the blood-corpuscles which it has entangled within itself while coagulating.

Authorities differ as to the nature of this so-called spontaneous coagulation, and for our present purpose it is not necessary to enter upon the subject.

When purified, as far as possible, from adhering impurities, blood-fibrin is a white, fibrous-looking, elastic substance, in which the microscope shows no traces of any structure, fibrous or otherwise.

Flesh-fibrin, the chief constituent of all muscular fibres, differs from blood-fibrin in the fact that it appears in organized structures in the form of variously shaped and grouped cells. Flesh-fibrin behaves, also, somewhat differently to chemical reagents from the coagulated blood-fibrin, but, like all insoluble modifications, it is easily converted by the action of the digestive fluids into a soluble form.

Casein is found in considerable quantity only in milk; it is a product of the milk-glands and therefore not to be looked upon as a constituent of the body in general. It does not coagulate on heating; the tenacious skin which forms on the surface of milk when it evaporates is a substance altered by the action of the air.

On the other hand, the casein separates almost completely in a coagulated state when a small quantity of rennet is added to the milk, as in making cheese, or when the milk is gently warmed with dilute acids or various other substances, as well as in the natural souring of milk.

Composition.—All the albuminoids contain, as essential constituents, carbon, hydrogen, oxygen, nitrogen, and sulphur; and these constituents are present in such constant quantities that it is impossible to distinguish the various albuminoids from each other by their percentage composition, samples of the same albuminoid from different sources often showing as great differences as exist between members of different groups. The following numbers show the extremes of variation:

Carbon	52–54	per cent.
Hydrogen	7	" "
Nitrogen	15–17	" "
Oxygen	24–21	" "
Sulphur	1–1.5	" "

Generally the average amount of nitrogen is assumed to be 16 per cent., and the total quantity of albuminoids in a substance is calculated by multiplying the percentage of nitrogen found by analysis by 6.25 ($6.25 \times 16 = 100$).

The phosphorus which always accompanies the albuminoids seems to be held only loosely as phosphoric acid, and not to be an essential ingredient of them.

GELATIGENOUS SUBSTANCES.—The gelatigenous substances constitute scarcely less of the weight of the body than the albuminoids.

They form the nitrogenous organic substance of bone and cartilage, and make up the larger part of the mass of the tendons, ligaments, and connective tissue, and of the skin. By protracted boiling with water the gelatigenous substances are completely dissolved, and converted into glue. Their composition is very similar to that of the albuminoids, except that they generally contain somewhat less carbon (50 to 51 per cent.), and in case of cartilage also less nitrogen (about 15 per cent.), while the gelatigenous substance of the bones, tendons, and skin, on the contrary, is richer in nitrogen (about 18 per cent.). The sulphur is also either entirely lacking, or is present in smaller quantity than in the albuminoids.

HORNY MATTERS.—The horny matters are found chiefly on the outer surface of the body, either in a thin layer, as the epidermis (scarf-skin), or in well-characterized tissues, as hair, wool, horns, nails, hoofs, claws, feathers, etc. The average composition of all these tissues is very uniform:

Carbon		50–51	per cent.
Hydrogen	about	7	"
Nitrogen		16–17	"
Oxygen		22–20	"
Sulphur		3–5	"

In the main, therefore, they differ from the albuminoids and gelatigenous substances only in containing more sulphur, while the proportions of the remaining constituents are almost the same.

AVERAGE COMPOSITION.—It will be seen that all the important nitrogenous substances which occur in the body are very similar and, on the average, almost identical in composition with the pure albuminoids out of which they were all formed, directly or indirectly, in the processes of nutrition and growth.

This agreement was also found in the investigations of Lawes and Gilbert on whole bodies of animals, already referred to. In these experiments the total quantity of water, fixed mineral matters, fat, and organic substances other than fat was determined, and the nitrogen of the latter was estimated.

The amount of "organic substances other than fat" found directly, agreed almost exactly with that obtained by multiplying the quantity of nitrogen found by the usual factor, 6.25; in other words, all the organic substances other than fat were found to contain, on the average, almost exactly 16 per cent. of nitrogen.

In the average of all the experiments, the organic matter other than fat was found to be 14.67 per cent. of the dressed weight, and the amount of albuminoids calculated from the nitrogen, 14.83 per cent. This shows at once that all the nitrogenous organic matters of the body aside from the three groups already mentioned, *e. g.*, certain constituents of the bile, of the juice of the muscles, etc., have, on account of their relatively small quantity, no material influence on the elementary composition of the organic substance of the body, and especially none on the percentage of nitrogen.

§ 4. INORGANIC, OR NON-VOLATILE MATTERS.

Amount.—The total quantity of the inorganic portion, or ash, of the animal body is, in round numbers,

In neat cattle...........	4–5	per cent.	of the live	weight.
" sheep................	2.8–3.5	"	"	"
" swine................	1.8–3.0	"	"	"

In lean animals the amount approaches the maximum, in fat animals the minimum. Phosphoric acid and lime are present in about equal proportions and make up together about four-fifths of the total quantity of ash, while the other fifth consists of potash, soda, magnesia, chlorine, sulphuric acid, carbonic acid, and, to a very minute extent, of silica.

The sulphur, mentioned above as forming part of all the important nitrogenous substances of the body, is not included in the ash.

In the bones, as is well-known, the quantity of mineral matter (bone-ash) is especially great, and amounts, on the average, in a full-grown animal, to about two-thirds of the dry, fat-free substance of the bones.

Immediately after birth, the dried bones contain only about 50 per cent., and in advanced age often as much as 75 per cent. of ash. The outer and more solid layers are always richer in ash than the inner and porous parts, especially in the hollow bones. At least seven-eighths of the total bone-ash is phosphate of lime, the remainder is carbonate of lime with small quantities of magnesia, fluorine, and soda.

Besides phosphoric acid and lime, the most important inorganic constituents of the body are potash, soda, and chlorine (the two latter generally combined to form chloride of sodium or common salt).

Need of a Continual Supply.—The quantity of these substances in the various tissues and fluids, while it is very constant, is relatively small, except in the case of the bones, but they are absolutely essential constituents of all those parts of the body in which the vital processes are most actively carried on, and in which, consequently, decomposition and rebuilding are continually taking place. As a consequence, they are continually excreted from the body in considerable quantities with the final products of the metamorphosis of tissue, and the vital processes would soon suffer important disturbances were not a continual, almost daily, supply provided.

Salt-hunger.—Numerous experiments have shown that when animals are fed on food from which the mineral matters (salts) have been extracted as completely as possible, they become sleepy, weak, especially in the extremities, and finally die from lack of mineral food, although the quantity of organic food eaten and digested may be amply sufficient to sustain life.

As an example of these may be mentioned some experiments made at the Physiological Institute of the University of Munich, by Forster,* on pigeons and dogs.

The pigeons were fed with starch and casein, made as free from ash as possible; the dogs with meat repeatedly extracted with water (to remove the mineral matters) and with fat, sometimes with addition of starch. The results were the same in every case. All the animals became, after a few days, in consequence of "salt-hunger," dull and inactive; a rapidly increasing weakness of the muscles appeared, particularly in the extremities, and toward the end of the experiment cramps and shivering showed a great irritability of the nervous system.

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* Zeitschr. f. Biologie, IX., 297.

The digestion, however, as well as the utilization of the digested nutrients, was exactly the same as under normal conditions, and the animals, when killed at the end of the experiments, were found to be apparently well nourished, and with all the organs in a healthy state.

We must conclude from these, and numerous other similar researches, that the phenomena of dulness and weakness observed in all such experiments are due directly and exclusively to the lack of inorganic ingredients in the food, and that the comparatively speedy death is caused by the separation from the animal organs and juices of those salts necessary for the due performance of their functions, and their removal from the body in the urine.

Essential and Accidental Salts.—The greater portion of the inorganic matters of the body exists, in combination with organic substances, as an essential constituent of the various tissues and juices. Strictly speaking, it forms part of the organic (or organized) portion of the body. Its amount is very constant. Another variable and much smaller portion, which we may call accidental, exists simply dissolved in the fluids of the body, without really forming part of it. This portion can never be very great, even with an abundant supply of salts in the food, since the latter are rapidly excreted in the urine, and the more rapidly the greater their quantity; while those salts which enter into the composition of the tissues can be excreted no faster than they are set at liberty by the using up of the tissue, and, in fact, even when thus set at liberty, may recombine, in part, with organic matter to form new tissue.

This latter fact is particularly noticeable when the food is poor in salts. Thus, it was found in the experiments already described (p. 21) that the excretion of salts was least when the food was most abundant but was poorest in salts, showing that nature can be very economical and get on with a minimum. There is a limit to this, however. The excretion of salts can be diminished but not entirely prevented, and if the supply of salts is too small, the animal loses mineral matter continually, and sooner or later dies.

Practical Conclusions.—In practice, in the feeding of mature animals intended to be kept in a medium condition, or to be fattened, a lack of the necessary mineral matters is scarcely ever to be feared. They are, indeed, generally present in large excess.

Only common salt is in certain respects an exception, as will be explained more fully below.

The opinion is indeed somewhat prevalent that a lack of phosphate of lime in the fodder may be the immediate cause of the disease, prevalent among cattle in some neighborhoods, called rickets.

This explanation is, however, at most, only valid in case this lack was experienced by the animal from its earliest youth up. In the case of full-grown and healthy animals, the lack of phosphate of lime cannot well be the cause of the disease, since experiment has shown that such animals, when they are insufficiently supplied with this substance, die in a comparatively short time, and before any essential change takes place in the composition of the bones.

Young and rapidly-growing animals naturally need, both relatively and absolutely, a greater quantity of phosphate of lime than old and full grown ones. In the feeding of milk cows, too, regard must be had to the quantity of phosphate of lime in the fodder. (See Part III., chapters V. and VI.)

Uses of Common Salt.—As mentioned above, salt occupies, to a certain extent, an exceptional position.

Besides its strictly physiological functions, it is of use in facilitating the passage of the albuminoids of the food from the digestive canal into the blood, and to a certain extent in facilitating the circulation and thus increasing the energy of the vital processes. For this purpose a certain excess of salt seems to be necessary, which circulates rapidly through the body, and is excreted in the urine in quantity corresponding to the amount taken. This need of salt is especially manifest in certain kinds of herbivora, and particularly in such as, like our domestic animals, are largely stall-fed and, by means of abundant fodder, are caused to produce largely either flesh and fat, milk, or work.

To this may be added that many fodders in common use, such as potatoes, roots, grains, etc., are comparatively poor in sodium chloride and rich in potash salts, which latter, it has been found, cause an increased excretion of salt through the urine.

In view, then, of the absolute demand for a certain amount of salt for the preservation of life and the great advantages of a certain excess of it, it is plain that it is to be regarded not as a luxury but as a necessity.

CHAPTER II.

COMPONENTS OF FODDERS.—NUTRIENTS.

§ 1. DEFINITIONS.

Nutrient, Fodder, Ration.—In the preceding chapter we have seen that the animal body, in spite of the great complexity of its structure, may be considered, in a general way, as composed of nitrogenous and non-nitrogenous organic substances, and of mineral matters.

Since, now, these substances are being constantly destroyed in the body in the performance of the vital functions, it is necessary that the animal should receive from without a supply of substances identical with or similar to those destroyed, and which can be assimilated by the tissues and fluids of the body to replace those lost and enable the vital actions to continue.

Any single chemical compound, such as albumin, fat, starch, sugar, etc., which is capable of aiding to replace this loss is called a *nutrient.*

Such substances do not occur in a pure, unmixed state in nature, but are found in various forms and proportions in all fodders.

By a *fodder*, or *feeding-stuff*, we understand any natural or artificial product which is used as food for animals; *e. g.*, hay, oil cake, roots.

Since the animal organism not only contains various nitrogenous and non-nitrogenous substances, but contains them in proportions varying only within narrow limits; and since the rate at which each is destroyed in the body is also fixed within certain limits; it is plain that the food which the animal receives must also contain the various nitrogenous and non-nitrogenous nutrients in proper proportions.

A *fodder* usually contains several or all of the groups of *nutrients*, but may not contain them in the proper proportions to satisfy the needs of the organism. Thus, in the examples given above, good hay contains all the groups of nutrients in proper proportions, and will sustain an herbivorous animal indefinitely; while oil cake and roots contain an excess, the one of albuminoids, the other of bodies of the starch or pectin groups, and so, if capable of sustaining life, do it with a great waste of the one or the other material. They are one-sided foods.

By combining several one-sided foods, we may prepare a mixture which shall contain all the groups of nutrients in proper proportions and be capable of sustaining an animal economically. Such a mixture we may call a *ration* or a *complete food*.

The proportions of the various nutrients in the common fodders and the proper combining of fodders to form rations suitable for various purposes will be treated of in Parts II. and III., and we shall concern ourselves here only with the occurrence and properties of the nutrients. These it is necessary to consider in order to a proper understanding of the processes of digestion and assimilation. The nutrients are divided into three groups, corresponding to the three groups of substances in the animal body, viz.: nitrogenous, non-nitrogenous, and mineral substances.

§ 2. NITROGENOUS NUTRIENTS.

PROTEIN. — The predominant nitrogenous constituents of plants resemble closely, in all important particulars, the albuminoids of the animal body, and have, like them, been called albuminoids or protein bodies.

The name *protein* was used by Mulder to designate a supposed substance which formed the basis of all the albuminoids. The word is no longer used in this sense, but is very commonly met with as a collective term for all the albuminoids, and we shall thus use it in the present work.

The vegetable albuminoids which have as yet been investigated may be divided into three groups, *albumin*, *casein*, and *fibrin*, having more or less resemblance to the corresponding groups of animal albuminoids, though it is doubtful if the two are identical.

Vegetable Albumin appears to occur chiefly in the young and growing parts of plants, while in the older parts it is converted into other forms of protein. It is contained, dissolved in small quantities, in the sap of fresh plants, and coagulates when the sap is heated.

Vegetable albumin is soluble in cold water, in dilute potash solution, and in dilute acetic acid; it is insoluble in alcohol, and is very similar in all its properties to animal albumin. Its composition varies somewhat according to the source from which it is derived. The following table shows the extremes of variation:

	Animal albumin (av.). Per cent.	Vegetable albumin. Per cent.
Carbon	53.5	52.3–54.3
Hydrogen	7.0	7.1– 7.7
Nitrogen	15.5	15.5–17.6
Oxygen	22.4	20.6–23.0
Sulphur	1.6	0.8– 1.6

The composition of animal albumin is not far from the average for vegetable albumin, but the identity of the two is, at best, doubtful.

Vegetable Casein.—If wheat flour be made into dough, and the dough kneaded in a stream of water, the starch of the flour is washed out, and a sticky mass remains, known as crude wheat-gluten.

The crude gluten thus obtained is a mixture of at least four albuminoids, and contains, besides, some starch and fat.

When treated with dilute (60 to 80 per cent.) alcohol at ordinary temperatures, three of these albuminoids are dissolved, while the fourth, called *gluten-casein*, remains behind, together with various impurities. The same or a very similar substance is also contained in rye, barley, and perhaps in buckwheat, and in the "oil seeds;" while oats contain an albuminoid having some of the properties of gluten-casein but more closely resembling the legumin about to be described.

In addition to *gluten-casein*, two other bodies belonging to the casein group have been described, viz.: *legumin*, the chief albuminoid of the seeds of the legumes (peas, beans, etc.), and *conglutin*, contained in almonds and in maize (?)

The properties of these albuminoids, and in particular those of *legumin*, resemble very closely those of animal casein. Legumin is insoluble in water. It is, however, quite soluble in water containing small quantities of basic phosphates, especially of potash, and hence warm water extracts legumin from the seeds of the legumes, since the latter contain soluble phosphates. Such a solution of legumin is not coagulated by heat, but is by acids, and according to one authority by rennet. Legumin is insoluble in either strong or dilute alcohol, but very readily soluble in dilute potash solution, and somewhat soluble in dilute acids. The reactions of gluten-casein, as well as those of conglutin, are very similar to those of legumin.

The composition of these albuminoids, like that of all others, varies more or less according to their source and mode of preparation, owing largely to the great difficulty of obtaining them in a pure state and in part perhaps, to the non-identity of substances bearing the same name but derived from different sources. The following table shows some of Ritthausen's results.*

	Gluten-casein. Per cent.	LEGUMIN FROM			CONGLUTIN FROM	
		Oats. Per cent.	Peas. Per cent.	Beans. Per cent.	Maize. Per cent.	Sweet almonds. Per cent.
Carbon	52.70–53.16	51.63	51.48	51.48	51.41	50.44
Hydrogen........	6.95– 7.15	7.49	7.02	6.96	7.19	6.85
Nitrogen	16.70–17.21	17.45	17.13	14.76 (?)	17.72	18.61
Oxygen..........	21.92–22.18	22.64	23.97	26.35	23.68	23.67
Sulphur..........	0.93– 1.27	0.79	0.40	0.45		0.43

Vegetable Fibrin.—When crude wheat gluten is treated with alcohol in the preparation of gluten-casein, as above described, a solution is obtained from which an albuminoid known as *gluten-fibrin* may be prepared as a tenacious, translucent substance of a brownish-yellow color.

It is insoluble in water or absolute alcohol; soluble in dilute alcohol, in dilute acids, and in dilute potash solution. When heated, it is converted into an insoluble modification, which is not dissolved by dilute acids or alkalies. The same or a similar substance is contained in barley and maize.

The composition of vegetable fibrin, like that of the other albuminoids, varies more or less. Ritthausen obtained the following results:

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* Die Eiweisskörper der Getreidearten, etc., 1872, and Jahresber. Agr. Chem., N. F., I., 168.

	From wheat. Per cent.	From barley. Per cent.	From maize. Per cent.
Carbon	54.31	54.55	54.69
Hydrogen	7.18	7.27	7.51
Nitrogen	16.89	15.70	16.33
Oxygen	20.61	22.48	20.78
Sulphur	1.01		0.69
	100.00	100.00	100.00

Mucedin and Gliadin.—Besides gluten-casein and gluten-fibrin, wheat gluten contains two other albuminoids, viz.: mucedin, and gliadin or vegetable glue.

Mucedin, when freshly prepared and containing water, is a yellowish-white, slimy substance, somewhat translucent and with a silky lustre. It is soluble in dilute alcohol, but insoluble in strong alcohol, which precipitates it from its solutions. Its behavior to water is peculiar. It is scarcely soluble, but when agitated with water, can be suspended in it, forming a turbid, slimy fluid, which, on long standing, deposits the mucedin unaltered. The same results are obtained if the water is warmed instead of stirred. Continued boiling with water decomposes mucedin, and alters most of it into an insoluble substance.

Gliadin very closely resembles animal glue in its properties. It is soluble in both weak and strong alcohol, in alkalies, and in acids. In cold water it swells up like glue; prolonged boiling with water decomposes it.

The composition of mucedin and gliadin obtained from wheat was found by Ritthausen to be:

	Mucedin—Per cent.	Gliadin—Per cent.
Carbon	45.11	52.67
Hydrogen	6.90	7.10
Nitrogen	16.63	18.01
Oxygen	21.48	21.57
Sulphur	0.88	0.85

Mucedin is also found in rye and barley, and gliadin in oats.

Other Albuminoids.—It will not have escaped notice that in the above paragraphs we have confined ourselves chiefly to a consideration of the albuminoids of the cereal grains and the legumes.

This is simply because these are the only vegetable products which have been investigated with any degree of completeness. Doubtless other feeding-stuffs would be found to contain still other varieties of protein, were they investigated, but at present we know little or nothing regarding them.

Comparative Value in Nutrition.—While the various albuminoids of the vegetable world vary not inconsiderably in their composition, especially as regards carbon and nitrogen, they still show such strong general resemblances, both in composition and properties, to each other and to the animal albuminoids, that we must consider them all as closely related bodies. Indeed they seem capable, to a certain extent, of conversion into each other in various ways.

Whether the various vegetable albuminoids are equally valuable as nutrients, are assimilated and formed into part of the body with equal ease, we are unable to say, owing to the entire lack of experiments on the subject. It is, perhaps, questionable if they are, but the differences, if they exist, are probably not great, and for the present we must consider them all as equivalent, so far as they are actually digested.

The recent experiments of Wildt * and of E. v. Wolff † on swine seem also to show that the animal albuminoids contained in dried blood and flesh-meal (the residue from the preparation of "Extract of meat,") are equivalent in nutritive effect to vegetable albuminoids.

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* Landw. Jahrbücher, VI., 177.

† Ibid., VIII., 223.

It is possible that we ought to regard gliadin as forming an exception to the equivalence of the albuminoids on account of its great likeness to animal glue, or gelatin, the latter having been shown by Voit* to be incapable of performing all the functions of protein in the food.

Importance.—This close mutual relation and easy convertibility of the albuminoids has the highest significance for animal nutrition.

As we have seen, the most important solid components of the animal body are the albuminoids and related bodies. It is these which constitute its muscles, tendons, nerves, in fact all its working machinery.

Now, so far as we know, the animal organism has no power to originate a particle of these substances.

Its sole source of them is, in the herbivora directly and in the carnivora indirectly, the albuminoids of the plant. These, by virtue of their great similarity to the animal albuminoids, are readily altered into them and become part of the body. They are hence indispensable elements of any food, and likewise the most important, since, while they can, to a certain extent, take the place of the non-nitrogenous nutrients, none of the latter can possibly replace the albuminoids; and they are of all the greater importance because, while the animal body is, to so large an extent, composed of them, they are found in comparatively small quantity in most parts of plants.

Evidently, then, the proportion of albuminoids which a fodder contains is an important element in determining its value; and those fodders which contain them in the largest quantity are, other things being equal, the most valuable, since the albuminoids are the most expensive ingredients to produce.

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* Zeitschrift f. Biologie, VIII., 297.

Occurrence in Plants.—This is not the place for a discussion of the composition of the various fodders, but a few general considerations regarding the distribution of the albuminoids in the plant may not be out of place.

In the plant, as in the animal, life manifests itself chiefly through the albuminoids, and consequently all young and growing plants and parts of plants contain them abundantly, while in the older portions, which have for the most part finished their growth, they are present in much smaller proportion, both owing to the increase of other substances, chiefly woody-fibre, and an actual transfer (translocation) of albuminoids to other parts of the plant. This is one reason of the greater nutritive value of young grass and green fodder in general, of hay cut while still young, etc. (See, however, page 299.)

In mature plants the albuminoids tend to accumulate in the seeds. Thus the grains, beans, peas, etc., contain large quantities of albuminoids and owe to them, in a large measure, their value as fodder, while the plants on which they grow, if allowed to stand till the seed is ripe, become correspondingly impoverished in these compounds.

In the case of the cereals, it is the seeds which we desire, and hence we allow the plant to mature.

On the other hand, in the case of the grasses, belonging to the same natural family (*gramineæ*), we use the whole plant as fodder, and hence cut it before the seed matures, because, although the whole amount of albuminoids is not decreased in ripening, it is largely stored up in the seeds, and these are mostly lost in the processes of curing, while such as are retained, owing to their small size, escape mastication and are not digested.

The proportion of albuminoids in the same species of plants and in the same parts of the plant differs according to the quality of the soil on which it is grown, the manuring, the weather, and other circumstances, so that it is only by means of numerous analyses that the average composition of any fodder can be ascertained. A discussion of these points and of the results of analyses of the more important fodders will be found in Part II.

OTHER NITROGENOUS CONSTITUENTS OF PLANTS.—Various nitrogenous substances not belonging to the albuminoid group have been found in plants. For our present purpose, we may divide them into four classes:

1. *Nitrates, nitrites, and ammonia salts;*
2. *Peptones;*
3. *Alkaloids;*
4. *Amines, amides, and amido-acids.*

Nitrates, Nitrites, and Ammonia Salts.—These substances usually occur very sparingly in plants, though beets, and probably other root crops, contain considerable quantities of them, and maize also frequently contains a not inconsiderable amount of nitrates. These substances, however, need hardly be taken into account here, since they have no nutritive value.

Peptones.—Recently, v. Gorup-Besanez has shown (*Ber. Deut. Chem. Ges.*, 1874, p. 1478) that the seeds of the vetch contain a ferment capable of converting starch into sugar and albuminoids into peptones,* and a similar substance has since been found in other seeds. It is highly probable that, during germination, these ferments act on the albuminoids of the seeds, converting them into peptones and so facilitating their translocation into the young plant. How extensively or in what amount peptones are to be found in plants, we have no certain knowledge.

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* See p. 59.

Alkaloids.—The term alkaloid (alkali-like) is applied to a class of organic bodies possessing more or less marked alkaline characters, a bitter taste, and poisonous or narcotic qualities. Morphine, strychnine, and nicotine, are common examples. These bodies, though quite widely distributed in the vegetable kingdom, occur in few of our ordinary fodder plants, the principal one being the lupine. Siewert (*Jahresber. f. Agr. Chem.*, 13–15, II. 6) found in the seeds of the yellow lupine 0.6 per cent. of alkaloids, and in those of the blue lupine 0.63 per cent., and H. Schulze (*Landw. Jahrbücher*, VIII., 37) obtained only 0.39 per cent.

Amines, Amides, and Amido-acids.—By these names the chemist understands certain nitrogenous organic substances, having a more or less close chemical resemblance to ammonia. When solid, they are generally crystalline and soluble in water, and pass easily through a moist membrane by the process of liquid diffusion, differing in these respects from the albuminoids, many of which are slightly or not at all soluble in water, and all of which are non-crystalline, and diffuse with extreme slowness. Most of them, when boiled with dilute acids or alkalies, give off their nitrogen, wholly or in part, as ammonia.

The first one to be discovered was asparagin (amido-succinamic acid) by Vauquelin and Robinet in 1805, in asparagus shoots. The same body has since been found in a large number of plants or parts of plants, and appears to be quite widely distributed in the vegetable kingdom.

Several other substances belonging to the same class have also been isolated. Scheibler[*] discovered betain (tri-methyl glycocoll) in mangolds, v. Gorup-Besanez[†] found leucin in germinating vetches, Schulze and Urich[‡] have shown that glutamin is contained in mangolds, and the same body, along with some tyrosin, was found by Schulze and Barbieri[§] in germinating squash seeds, and it is highly probable that other similar bodies will yet be isolated.

Functions in the Plant.—The investigations of Pfeffer[‖] on asparagin showed that this body was abundantly formed, during the germination of leguminous plants, by the splitting up of the protein of the seed, and, after being dissolved in the water always present and thus transferred to the young plant, was reconverted into protein. That is, it served, by virtue of its solubility and diffusibility, to render available to the plant the insoluble albuminoids of the seed. Later researches by E. Schulze,[¶] and especially by Borodin,[**] seem, however, to show that the formation of asparagin is not limited to germination, but that the transfer of protein from one part of the plant to another which is continually taking place during growth is also effected by the agency of this and other amides.

Borodin also believes that asparagin (and other like bodies?) is being continually produced in the living plant. According to him, the respiration of the plant takes place at the expense of the albuminoids of the protoplasm, which are decomposed with formation of asparagin. Under normal conditions, the latter is regenerated to protein, but under certain circumstances it may accumulate in the plant.

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[*] Zeitschrift für Rübenzucker-Industrie, XVI., 229.

[†] Ber. Deut. Chem. Ges., VII., 147.

[‡] Versuchs-Stationen, XX., 193.

[§] Landw. Jahrbücher, VI., 681.

[‖] Jahrbücher für Wiss. Botanik, VIII., 530.

[¶] Landw. Jahrbücher, VII., 411.

[**] Botanische Zeitung, Jahrg. 36, Nr. 51 and 52.

According to Schulze, various amides are formed in this process, some of which are rapidly regenerated, while others are utilized but slowly, and hence accumulate in comparatively large quantities.

This view is supported by the results of Kellner,* who found a considerable amount of amides in a large number of growing plants. His experiments were made chiefly on fodder plants, in some of which over 30 per cent. of the total nitrogen was found to exist in amide form, but considerable quantities of these bodies were also found in the green parts of several species of trees.

Furthermore, Schulze and Urich † have shown that beets, and, presumably, other roots, contain large quantities of amides, and that in the second year's growth they pass into the plant and serve as a source of protein.

Amides have also been found in considerable amounts in potatoes, where they doubtless perform a similar function.

It is but recently that investigation into the proportion of amides in fodder-plants has been begun, and our knowledge of the extent of their occurrence is still quite limited. In view of the importance of the matter, it is earnestly to be desired that it should receive a speedy and thorough investigation, extending at least so far as to determine the average proportion of albuminoids and non-albuminoids in our common feeding-stuffs.

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* Landw. Jahrbücher, VIII., I. Supplement, 243.

† Versuchs-Stationen, XX., 214.

§ 3. NON-NITROGENOUS NUTRIENTS.

CARBHYDRATES.—The chief substances composing this group of non-nitrogenous nutrients are *cellulose*, or *woody-fibre; starch; dextrine; cane, grape, milk, and fruit sugar;* and the *gums*. "These bodies, especially cellulose and starch, form by far the larger share of all the dry matter of vegetation, and most of them are distributed through all parts of plants." They owe their name to the fact that they all contain, besides carbon, the elements hydrogen and oxygen in the proportions in which the latter exist in water. This similarity of composition and their ready transformation into each other, both artificially and in the plant, show that they are nearly related chemically.

Cellulose.—All plants consist of cells or microscopic closed sacks or tubes adhering together. The walls of these cells are composed of cellulose, and hence the latter is a constituent of all vegetable tissue, constituting, as it were, its frame-work. In those parts of the plant where greater strength is needed, the originally thin walls of the cells increase greatly in thickness, and often become impregnated with a harder substance or substances known as lignin, making them still tougher. This is especially the case with the stems. Foliage, and the husks, etc., of fruits, also contain much cellulose.

Properties.—Pure cellulose is an odorless and tasteless solid, varying somewhat in appearance, according to its source, but usually white in color, and with a silky or horny lustre. Cotton, flax, and hemp, and cloth and unsized paper made from them are examples of nearly pure cellulose.

It is distinguished from the other bodies of this group by its slight solubility; neither dilute acids nor alkalies, water, or any of the ordinary solvents, dissolve it. Hence, it may be obtained by acting on vegetable matter with various solvents till all other substances are removed.

If cellulose be exposed for some time to the action of strong oil-of-vitriol, or be boiled for some hours with dilute acids or alkalies, it is converted first into dextrine and then into grape-sugar. If treated with iodine and then with strong sulphuric acid, it assumes a deep-blue color. This reaction serves to identify cellulose under the microscope.

Composition.—Pure cellulose has exactly the same composition as starch, viz.:

Carbon	44.44	per cent.
Hydrogen	6.17	"
Oxygen	49.39	"
	100.00	

As intimated above, however, it is seldom found pure, except in the young and tender parts of plants, but is usually more or less impregnated with substances to which the collective name of lignin has been given, and the following composition assigned:

Carbon	55.3	per cent.
Hydrogen	5.8	"
Oxygen	38.9	"
	100.0	

This is, however, simply the inferred composition of what is left after cellulose has been removed, and not the result of direct analysis. But it is certain that lignin (using the name in a collective sense) is richer in carbon than cellulose, and as a membrane becomes impregnated with the former, its percentage of that element increases.

Digestibility.—Cellulose was long thought to be indigestible.

Haubner * was the first to show that this belief was erroneous, and that the ruminants were capable of digesting large quantities of this substance. His results have since been verified in innumerable digestion experiments, which have shown that cellulose forms an important ingredient in the fodder, not only of ruminants, but of all our herbivorous domestic animals.

The proportion of cellulose which is digested varies very considerably according to the kind and quality of the fodder and the species of animal to which it is fed.

Of the cellulose of the ordinary coarse fodders, from about 30 to 70 per cent. is digested by ruminants, while the cellulose of the cereal grains seems much less digestible. In general, the younger and more tender a feeding-stuff is, the greater is the amount of cellulose which is digested, while in old and woody plants, in which much lignin is formed, its digestibility is considerably less. The lignin itself appears to be entirely indigestible.

Determination.—The amount of cellulose in a fodder is usually determined by successively boiling the finely divided material with dilute acid and dilute alkali, and washing with alcohol and ether. These solvents remove the other constituents of the fodder and leave the (impure) cellulose behind. The residue, after deduction of the small quantities of ash and albuminoids which it still contains, is designated as *crude fibre.*

It is by no means pure cellulose, but is chiefly a mixture of the latter with lignin. The crude fibre obtained from different fodders according to this method has a varying appearance and composition; the crude fibre, *e. g.*, prepared from hay and straw, contains 45 to 46 per cent. of carbon, while that from clover hay and the straw of the legumes contains 48 to 49 per cent. of the same element; that is, the latter is richer in lignin than the former.

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* Amts- und Anzeigeblatt f. d. landw. Vereine des Königreichs Sachsen, 1854, Nr. 6; also, Zeitschr. f. D. Landw. 1855, 177.

It is evident from these considerations that the crude fibre is not a definite body, but a variable mixture of several substances. The method just described is, indeed, simply a conventional one, agreed on by chemists for lack of a better, and the term crude fibre simply means the residue obtained by treating the fodder in the prescribed manner.

The results, especially when combined with digestion experiments, are of great value, but it is still much to be regretted that no more accurate method has yet been devised.

Starch.—Next to water and cellulose, starch is the most abundant substance in the vegetable world, being found in all plants and in almost all parts of them. It appears to be first formed in the green leaves, as the product of the reduction of the carbonic acid of the air under the influence of sunlight, and from thence to be distributed, by a process of solution and redeposition, to all the organs of the plant. It is found in large quantity in the seeds of the cereals, wheat, *e. g.*, containing 61 to 76 per cent. of it in the dry substance, and constitutes a large proportion of the dry matter of potatoes and other tubers.*

Properties.—Pure starch is an odorless and tasteless white powder, which, when examined under the microscope, is seen to consist of minute organized grains. These starch grains are formed in the plant by a process of growth, and vary in size and appearance according to the species of plant which produces them, so that starch from different sources can be readily distinguished.

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* The artichoke and some other tubers contain, instead of starch, a body closely resembling it, called inulin. Inulin exists in plants both as a liquid and in grains. It gives no coloration with iodine.

They are composed of two substances—a skeleton of a material resembling cellulose and called *starch-cellulose*, and a more soluble substance called *granulose*, which constitutes by far the larger part of the grains. A characteristic property of starch is that, when brought in contact with a minute quantity of iodine in solution, it assumes a beautiful blue color. This property seems to reside in the granulose, since, if this be removed by solvents, the residue gives no longer a blue but a yellow color with iodine, like ordinary cellulose.

Starch is insoluble in cold water so long as the grains remain whole. If they are crushed and ground very fine with water, a minute quantity is dissolved.

When heated with water nearly to boiling, the grains swell and burst, absorbing water and forming a jelly-like mass, but very little starch is really dissolved by this treatment.

Starch, like cellulose, may be converted into dextrine and grape-sugar by boiling with acids or alkalies, but much more readily. The same transformation may be effected by dry heat, and by the action of diastase,* the ferment of malt, as in the preparation of beer and spirits.

It is also rapidly dissolved and converted into sugar by the action of the saliva of the mouth and by the pancreatic juice, and is, indeed, one of the most important of the non-nitrogenous nutrients, owing to its abundance and the comparative ease and completeness with which it is digested.

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* Diastase produces a peculiar kind of sugar called *maltose*, instead of grape-sugar.

The composition of dry starch is the same as that of cellulose, viz.:

Carbon	44.44
Hydrogen	6.17
Oxygen	49.39
	100.00

In the air-dry state it contains 12 to 20 per cent. of water.

Dextrine seldom has been found in plants, at least in any considerable quantity, and is chiefly interesting in this connection on account of its relations to starch and sugar. It is prepared commercially in large quantities, under the name of British gum, by the action of dry heat on starch. It is formed in the same way from starch during the baking of bread, and is an important ingredient of food prepared by cooking materials containing starch. It appears to be entirely digestible.

The Sugars.—There are four principal kinds of sugar, viz.: *cane-sugar*, obtained from the juice of the sugar-cane, the sugar-beet, sugar-maple, and other plants, and forming the ordinary sugar of commerce; *milk-sugar*, occurring in the milk of mammalia; and *grape-sugar* and *fruit-sugar*, usually occurring together in the juices of plants and sweet fruits and in honey. Grape-sugar is also known as glucose and dextrose, and fruit-sugar as levulose.

These sugars have the following composition:

	Carbon. Per cent.	Hydrogen. Per cent.	Oxygen. Per cent.
Cane-sugar Milk-sugar	42.11	6.43	51.46
Grape-sugar Fruit-sugar	40.00	6.67	53.33

They all resemble, in a general way, cane-sugar in their properties, though they are by no means identical.

For our present purpose, it is sufficient to say that they are all readily soluble in water, and hence easily digestible. They are important nutrients, being formed in large quantities, in digestion, from other carbhydrates, though in the ordinary fodders they occur in only small quantity.

The Gums.—Another group of substances of considerable importance is the gums, of which gum-arabic may be taken as a representative.

They are found in small proportions in various vegetable products, and in considerable quantity in the ordinary bread grains. They appear to be digestible by domestic animals, but of their value as nutrients we know as yet but little. Probably, however, they are practically about equivalent to starch.

Mutual Relations of the Carbhydrates.—The close relationship between the several members of this group of substances which is indicated by their analogous composition is shown still more plainly both by their ready conversion one into another, in nature and in the laboratory, and by their behavior to various reagents.

In the plant, starch seems to be the first formed, and from it all the other carbhydrates are produced, while these may be converted back again into starch.

In germination, the starch of the seed is converted into dextrine and sugar, which are carried in solution to the young plant, there to form cellulose or be reconverted into starch. In older plants, cellulose may be dissolved or converted into gum or vegetable mucilage.

In the laboratory, all the various carbhydrates are finally converted by heat or by boiling with acids or alkalies, first into dextrine and then into some form of sugar.

The close relationship between starch and cellulose is also shown by their behavior toward iodine. As we have seen, starch is colored blue by this reagent, while cellulose requires the addition of sulphuric acid (or one of several other substances) to produce the blue color.

It is only the *granulose* of starch, however, which gives a blue with iodine, while the *starch-cellulose* behaves like ordinary cellulose, and, on the other hand, J. Kühn* has shown that the cotyledons of the flax-seed contain a form of cellulose which is colored blue by iodine alone.

Indeed, the most recent investigations seem to show that there is a numerous series of carbhydrates, varying from the most insoluble and resistent to the most soluble and easily attacked forms, and capable of mutual interconversion in the plant and, to a certain extent, out of it.

THE PECTIN SUBSTANCES.—This group includes a number of bodies of rather uncertain composition, which are the characteristic ingredients of fruit-jellies. They are found in ripe fruits, and, together with sugar, constitute the larger part of the non-nitrogenous organic matter of the common root crops. Uncooked fruits and roots are supposed to contain a body called pectose, which, on boiling with water or exposure to heat, is converted into pectin, which is soft and soluble in water. It is this change which takes place in the cooking of fruit.

By further heating, the pectin is converted into pectic and pectosic acids. These substances are insoluble in cold water, and constitute the essential part of fruit-jelly. Pectosic acid is soluble in boiling water, and hence most jellies become liquid on heating; on cooling, its solution gelatinizes again. Pectic acid is insoluble, even in boiling water.

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* Ernährung des Rindviehes, 6th ed., p. 49.

By long-continued boiling, all these bodies are converted into metapectic acid, which is quite soluble and has a sour taste.

All these bodies are digestible, and are not unimportant as nutrients. They probably play much the same part in nutrition as the carbhydrates.

THE FATS.—**Composition.**—The fats found in plants have essentially the same composition as that possessed by those occurring in the animal body, and already noted on page 12, viz., on an average:

Carbon	76.5	per cent.
Hydrogen	12.0	"
Oxygen	11.5	"
	100.0	

It will be noticed that these nutrients differ from those hitherto considered in containing a much larger proportion of carbon and a much smaller one of oxygen. They consequently require much more oxygen for their complete combustion and give out about two and one-half times as much heat in burning as the carbhydrates, a fact of great importance in connection with the production of animal heat, and which will be treated of more fully in a subsequent chapter.

Occurrence.—Fat is found in small quantities in almost all plants.

In roots we find 0.1 to 0.2 per cent.; in hay and straw, 1.0 to 3.0 per cent.; in the cereal grains, 1.5 to 3.0 per cent., except in oats, which contain as much as 6 per cent.; and in maize about 4 to 9 per cent. It is especially, however, in the seeds of certain plants that fat or oil occurs.

The seeds of flax, hemp, colza, cotton, and numerous other plants, contain from 10 to 40 per cent. of oil, accompanied generally by a considerable quantity of protein.

The oil forms an article of commerce, and is commonly obtained by simply pressing the seeds.

By this process, however, it is impossible to separate all the fat, and in the residue of the manufacture—oil cake, rape cake, cotton-seed cake, etc.—there is left a considerable amount (8 to 12 per cent.) of oil, together with nearly all the albuminoids, and hence, owing to the importance of both classes of nutrients, these residues constitute most valuable fodder materials.

Sometimes the oil is extracted by means of solution in bisulphide of carbon instead of by pressing. In this case the residue is valuable chiefly on account of its albuminoids, the fat content being reduced to from 2 to 4 per cent.

Value.—In the ordinary fodder of our domestic animals fat plays a rather subordinate part, but in rapid fattening it is a most important aid, though, as we shall see, it is by no means the sole source of fat to the animal body. In addition to its direct nutritive effect, it also aids in the digestion and resorption of the important albuminoids.

§ 4. INORGANIC NUTRIENTS.

These comprise the substances found in the ashes of plants—the so-called inorganic or mineral constituents. The need of these in the animal organism and their functions, so far as known, have been already sufficiently spoken of in Chapter I. In all ordinary cases a ration which contains sufficient organic nutrients will also contain an abundance of the inorganic, so that commonly no special consideration of the quantity of the latter is necessary, with the exception of common salt, which, for reasons already given, is needed in larger amounts than those contained in most fodders.

Such being the case it is not necessary, for the purposes of the present work, to do more than mention these substances.

§ 5. Fodder Analysis.

In the preceding sections we have indicated briefly the occurrence and properties of the most important nutrients.

It only remains to describe, in a general way, the usual methods of determining the amount of these present in any fodder.

In the present state of our knowledge it is impossible, even were it necessary, to separate and determine *all* the multitudinous substances which may occur in a fodder, and we must content ourselves with distinguishing the several groups of nutrients.

Albuminoids.—The amount of albuminoids in a fodder has generally been found by multiplying its content of nitrogen by 6.25, it being assumed, first, that all the albuminoids contain 16 per cent. of nitrogen, and, second, that no other nitrogenous substances are present.

Neither of these assumptions being, as we have seen, strictly true, it follows that the result can only be approximate, and in view of this fact it is designated as *crude protein*.

Of the two sources of error arising under the above assumptions, the second is the more serious. It is only within a very short time that feeding-stuffs have begun to be examined for amides, but the results already obtained show that these bodies are to be found far more extensively, and in greater quantity, in feeding-stuffs than was before suspected. This is especially the case with those fodders which, like hay, and coarse fodders in general, are cut when still immature, and with roots; while the grains appear to contain practically all their nitrogen in the form of protein.

In the present state of our knowledge a simple determination of the total nitrogen of a fodder is not sufficient, but either the amide-nitrogen must be determined or the protein must be separated from the other nitrogenous matters, by some one of the numerous methods which have been proposed, and a separate estimation of its nitrogen made.

The error arising from the somewhat variable composition of the numerous vegetable albuminoids we have, unfortunately, no means of correcting. In the present state of our knowledge, it is impossible to fix upon separate factors, either for the several albuminoids or for different classes of feeding-stuffs, since the same albuminoid may vary considerably in composition according to its source or mode of preparation, and since the proportions in which these albuminoids are contained in the same vegetable product also vary. Moreover, we have no knowledge whatever regarding the composition of the albuminoids of an important class of feeding-stuffs, the so-called coarse fodders.

For the present we are obliged to continue the use of the conventional factor 6.25, bearing always in mind that it is but an approximation to the truth, though probably in most cases a tolerably close approximation.

Amides.—For the determination of amides Sachsse's method is generally used. The details of the method are too technical to find a place here; a description of the two processes proposed by Sachsse may be found in his book, "*Die Chemie und Physiologie der Farbstoffe, Kohlehydrate* *und Proteinsubstanzen,*" Leipzig, 1877, pp. 256 and 258, and a combination of the two methods, as proposed by E. Schulze, in "*Die Landwirthschaftlichen Versuchs-Stationen,* XX., 117.

Cellulose, as already stated (page 40), is determined by removing other substances, so far as possible, by boiling with dilute acid and alkali, washing with alcohol and ether, and deducting from the weight of the residue the ash and albuminoids which it still contains. The result gives the amount of *crude fibre.*

Fat is determined by dissolving it out of the dried fodder by extraction with renewed quantities of common (dry) ether, evaporating off the ether from the resulting solution, and weighing the fat remaining after careful drying at 100° C.

The ether extract of most grains and the residues from them can be considered as tolerably pure fat, but that of all green and coarse fodders, such as hay, straw, stover, etc., consists of a mixture of the most various substances, among which, along with the real fat, numerous wax and tar-like bodies, and especially leaf-green, or chlorophyll, occur in varying quantity. These substances are certainly of very varying importance, and in part are entirely indigestible.

Ash.—The mineral matter, or ash, of a fodder is determined by carefully burning a weighed quantity at as low a temperature as possible, to avoid volatilization of alkaline chlorides.

From the ash thus obtained is deducted any particles of coal which it contains, and also the carbonic acid, since the latter is only formed in the burning of the organic matter, and is often very variable in quantity, according to the temperature at which the ash is prepared, so that it is not properly a constituent of the latter.

Nitrogen-free Extract.—All that remains of the dry matter of the fodder, after deducting the crude protein, crude fibre, crude fat, and ash, is designated as nitrogen-free extract (N. fr. Extr.); that is, the quantity of the latter is determined by difference.

In all grains and roots this is of a tolerably simple nature, and consists chiefly of starch or sugar and bodies of the pectin group, and sometimes of vegetable mucilage, which has a composition analogous to that of starch and exerts, probably, an equal nutritive effect.

But in green and coarse fodders we have, in addition, varying quantities of gum-like substances and of lignin, which latter partly dissolves when the fodder is treated with acids and alkalies, but, at the same time, appears not to be resorbed in the alimentary canal, and therefore not to contribute to the nourishment of the animal.

On the other hand, we shall see further on that all of the nitrogen-free extract which is really digested has the percentage composition of starch, and that, therefore, the non-nitrogenous nutrients of fodders, with the exception of fat, may be considered in general as carbhydrates.

The small quantities of organic acids and other bodies present are of no direct importance as nutrients, though they often have an important indirect influence, either by imparting to the fodder an agreeable taste or smell, or the reverse, by some specific physiological action, or by imparting undesirable properties to the products of the animal —*e. g.*, the well-known effect of cabbage, rape cake, or onions on milk.

Nutritive Ratio.—Along with the composition of a fodder we usually find given its *nutritive ratio*, by which we understand the ratio of the digestible protein to the digestible non-nitrogenous nutrients.

From the results of large numbers of digestion experiments, we are able to tell, with a good degree of certainty, what percentage of the several nutrients of any fodder is digestible, and these results are to be found in tables of "digestion coefficients."

Suppose, now, that we have the analysis of a sample of average meadow hay of the following composition:

Water	14.3	per cent.
Ash	6.2	"
Protein	9.7	"
Crude-fibre	26.3	"
Nitrogen-free extract	41.0	"
Fat	2.5	"
	100.0	

The average of all available experiments shows that the following proportions of the different nutrients are digestible:

Protein	56	per cent.
Crude-fibre	57	"
Nitrogen-free extract	63	"
Fat	48	"

We therefore multiply the amount of each nutrient contained in the fodder by the corresponding digestion coefficient, and obtain the following results:

Digestible protein............ $= 9.7 \times 0.56 = 5.4$ per cent.
" crude-fibre.......... $= 26.3 \times 0.57 = 15.0$ "
" extract............ $= 41.0 \times 0.63 = 25.8$ "
" fat................ $= 2.5 \times 0.48 = 1.2$ "

The digestible portions of the crude-fibre and nitrogen-free extract have been shown to have the composition of starch, and may be considered as of equal nutritive value, pound for pound; but the fat produces a greater effect in the body than an equal weight of carbhydrates, and this fact must be taken into account. It was formerly believed that the non-nitrogenous nutrients served chiefly as fuel in the body to maintain the animal heat, and that since a pound of fat yields two and one-half times as much heat when burned as a pound of starch, it was therefore two and one-half times as valuable a food, and hence, in calculating nutritive ratios, the fat was reduced to its "starch equivalent" by multiplication by 2½. We now know that this is but a partial and, for purposes of feeding, a misleading view, and it is probable that in time the present factor, 2½, will be replaced by a more correct one; but that time is not yet, and, in the meantime, we must follow established custom, for the sake of rendering our analyses comparable with others.

We therefore make the following calculation:

Digestible fat × 2½	= 3.0
Digestible fibre	=15.0
Digestible extract	=25.8
	43.8
Digestible protein	= 5.4

The nutritive ratio, then, is 5.4 : 43.8, or 1 : 8.1; the quantity of digestible protein being usually taken as unity.

CHAPTER III.

DIGESTION AND RESORPTION.

§ 1. Digestion.

Introductory.—The nutrients described in the preceding chapter, as they occur in the ordinary fodders, are not in suitable condition to become at once part of the body. They must be separated from the various useless substances with which they are associated, and be converted into soluble forms, before they can be taken up into the circulation and so serve to nourish the body;—that is, they must be digested.

"The digestive apparatus has been compared to the fittings of a pharmaceutist's laboratory in which extracts are prepared from organic substances. As, there, the mass to be extracted is pulverized by mortars, rasps, knives, and similar tools, so are the feeding-stuffs by the teeth of the animal; what is effected there by water, alcohol, ether, and other extracting fluids, the digestive juices which are secreted by various glands, and with which the whole mass to be digested is saturated, do in the animal body.

"As, in the laboratory, the sufficiently extracted materials are filtered to obtain the finished extract, so the filtration of the extracted nutrients in the animal body takes place through the membranes of the intestines.

"In the laboratory, the finished extract is received into a suitable vessel, and the worthless residue is thrown away; in the body, the blood and lymph vessels receive the extracted nutrients, while the undissolved residue, which has no nutritive value, is removed from the body in the form of the solid excrements.

"There exists, however, one great difference between the extracts prepared in the laboratory and those produced in the animal organism; the former contain, unaltered, the soluble matters which were present in the crude materials, while the constituents of the latter are essentially different from those contained in the food.

"This difference is due to the fact that the action of the digestive fluids is a more energetic one, and is accompanied by a chemical alteration of the dissolved substances."—(*Settegast.*)

Mastication and Insalivation.—The process of digestion takes place in the alimentary canal, consisting of the mouth, gullet, stomach, and small and large intestines.

The first step in the process takes place in the mouth, and consists, in the first place, of the act of mastication, by which the food is broken up and thus made to expose more surface to the action of the digestive fluids. At the same time certain glands (salivary glands), opening into the mouth, pour out abundantly a fluid known as the saliva. The secretion of the different salivary glands varies considerably in appearance and properties. The mixed saliva, as it is found in the mouth, is a watery, alkaline, somewhat slimy, transparent or slightly turbid fluid, containing from one-half to one per cent. of solid matter. This fluid is mixed thoroughly with the food during mastication, and serves to moisten and soften it and so to bring it into a suitable condition to be swallowed and further acted upon.

Besides moistening the food, however, the saliva contains a ferment, called *ptyalin*, which has the power, at the temperature of the body, of acting upon starch with very much the same results as boiling dilute acids or alkalies, viz., converting it into a form of sugar, *i. e.*, a soluble substance which can easily pass into the circulation. To how great an extent this action takes place is a somewhat disputed point, but there seems to be little doubt that it is at least of some consequence, though it by no means completes the digestion of the starch, especially in animals having a simple stomach. Moreover, the saliva, being a very watery secretion, dissolves the soluble matters of the food, and forms, to a certain extent, an aqueous extract of it.

Rumination.—From the mouth, the food, after being formed into morsels by the tongue, passes through the gullet to the stomach.

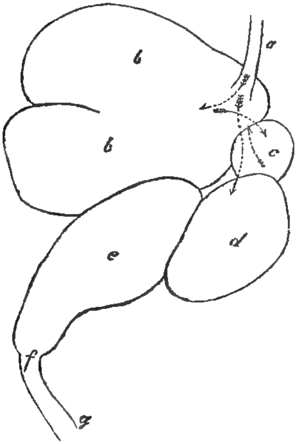

FIG. 2.—(J. Kühn.)

In animals with a simple stomach, the horse or hog, *e. g.*, the acts of mastication and insalivation are performed completely at first, but in the case of animals that chew the cud (ruminants), the food is at first only slightly chewed, and then passes into one of the divisions of their compound stomach.

The stomach of the ruminants consists of four divisions, as shown in outline in fig. 2.

The slightly-chewed masses pass first through the gullet, *a*, into the largest division of the stomach, the *paunch* or first stomach, *bb*, and partly also into the second stomach or *reticulum*, *c*.

Here they remain for a time, until softened by the saliva and the alkaline fluid secreted by the stomach itself. What is dissolved here passes directly on through the other divisions of the stomach, while the undissolved substances pass, a portion at a time, into the gullet, and are returned to the mouth to be thoroughly chewed and mixed with saliva.

From the opening of the gullet into the first stomach, a passage called the *œsophogean demi-canal* leads by the paunch and reticulum to the third stomach. This canal may be described as a continuation of the gullet, having a slit in its lower wall which forms an opening into the first and second stomachs.

When the food is swallowed the first time, its bulk seems to open the slit in the canal so that it passes into these two stomachs as already stated.

When swallowed the second time, a portion of it passes through this slit back into the first and second stomachs, but much of it goes on into the third stomach (*omasum* or *manifolds*), *d*, from which it does not return again to the mouth.

The interior surface of this division of the stomach is composed of numerous folds of mucous membrane, between which the food is received and subjected to more or less mechanical action, while the numerous capillary blood-vessels which the folds contain take up whatever materials are dissolved.

From the omasum the food passes to the fourth stomach, *abomasum* or *rennet*, *e*, there to undergo the ordinary processes of digestion in the same manner as in animals with a simple stomach.

So long as the young animal lives on milk alone, the first three divisions of the stomach remain undeveloped, and the food passes directly into the fourth; but as it begins to eat more voluminous food the first three are developed and begin their functions.

Liquid foods, in the full-grown animal, pass partly into all four stomachs.

The ruminants are thus especially adapted by nature to digest and utilize large volumes of coarse and relatively poor fodder, straw *e. g.*, and to extract from them the nutrients which they contain.

The opinion has been almost universally held that a certain volume of fodder is essential to the well-being of ruminating animals, and that, when concentrated feeding-stuffs are used, they must be supplemented by a suitable amount of coarse fodder, such as hay or straw, in order that the important function of rumination may not be disturbed.

There is no doubt that a bulky fodder is the natural food of ruminants, but the somewhat famous experiments of Mr. Linus W. Miller, of Stockton, N. Y., seem to show that rumination may be suspended for a considerable time with no injurious results.

Mr. Miller states that for several years he has successfully wintered his cows on corn-meal exclusively, feeding about three quarts per day and head, and that, although rumination has been entirely suspended for some months, no ill-effects were observed. Several others have also tried his system with favorable results.

The question of the sufficiency of such a ration we shall consider further on, but although the experiments have been the object of much criticism they certainly seem to show that a bulky fodder is not so essential to ruminants as has been supposed.

Naturally, however, coarse fodders will continue to form the basis for the rations of our farm animals under most circumstances; and since, in that case, the process of digestion is a complicated and a slow one, the animals should be allowed the necessary time and repose to complete the act of rumination undisturbed.

Gastric Digestion.—In the fourth stomach of ruminants and the simple stomach of other animals, the food is subjected to the action of the *gastric juice*. This fluid is produced by innumerable small glands, imbedded in the inner coat of the stomach, which, when excited by the presence of solid matter in the latter, pour out abundantly a clear, colorless fluid, having a sour taste and smell, and containing two characteristic ingredients.

One of these is *muriatic acid*, the chlorine of which comes from the salt of the food ; the other is *pepsin*, an organic substance about whose composition and properties little is known with certainty, but which acts powerfully, at the temperature of the body, on the albuminoids of the food.

Its first effect on the *soluble* albuminoids is to coagulate them. Afterward, however, the pepsin, in the presence of the muriatic acid of the gastric juice, acts on the coagulated or the originally solid albuminoids, and converts them into substances called *peptones*, having much the same properties as protein, but soluble in water, and hence easily taken up into the circulation.

The formation of peptones from albuminoids seems to be accomplished by the assimilation by the latter of the elements of water, being similar to the formation of dextrine and sugar from starch by the action of acids or alkalies. Indeed, albumin, when treated with acids, yields peptones.

According to Hoppe-Seyler,* the chief action of pepsin consists in this, that it unites with the muriatic acid present, transfers it to the protein, unites with a fresh quantity, transfers this, again, to the protein, and so on to an indefinite extent.

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* "Physiologische Chemie," 1878, p. 231.

If this be true, the similarity between the action of the gastric juice and that of acids is very close.

The quantity of pepsin concerned in this process is very small, and it is found that the same pepsin is capable of acting over and over again and converting apparently unlimited quantities of albuminoids into peptones, provided that more acid is added from time to time.

It is stated that the digestion of the albuminoids by the pepsin and muriatic acid of the gastric juice, and their conversion into soluble peptones, is facilitated by the presence of a little fat in the food, and by salt, which causes an increased secretion of the gastric juice.

It is hindered by dilution of the gastric juice by large amounts of drink, and too high or too low a temperature of the drink may, by destroying the pepsin, suspend the digestion altogether, until new pepsin can be secreted.

The action of the gastric juice on the food is aided by a peculiar action of the involuntary muscles which form one of the coats of the stomach. These keep the food continually in motion in the stomach, and in this way mix it thoroughly with the gastric juice, so that all parts of it may be acted upon.

By means of the gastric juice, aided by the motion of the stomach just described, portions of the food are dissolved, and the whole converted into a more or less fluid mass called *chyme*.

A portion of the chyme is resorbed in the stomach, and passes directly or indirectly into the circulation. This is the case with the sugar produced from the carbhydrates of the food by the saliva, with the vegetable acids, and in general with the easily soluble constituents of the chyme, and with water. They are largely (not entirely) taken up by the blood-vessels of the stomach. Some of the peptones are also resorbed in the stomach, though not into the blood-vessels but into the lymphatics, but a large part of them, along with the portions of the food not yet acted on, leaves the stomach through a valve, called the *pylorus*, at its lower end (*f*, fig. 2), and passes into the intestines (*g*, fig. 2).

Intestinal Digestion.—*The intestines* form a long tube, folded and bent many times upon itself, which, together with the stomach, liver, and a few other organs, fills the cavity of the abdomen.

Its length varies very considerably in different animals. In carnivorous animals, which live on easily-digested and concentrated food, it is from four to six times the length of the body; while in herbivorous animals, which feed on voluminous fodder, it is very much longer, being ten to twelve times the length of the body in the horse, twenty times in the ox, and twenty-five to twenty-six times in the goat. It is divided into two principal parts—the small intestine, beginning with the stomach and forming about $\frac{2}{3}$ to $\frac{4}{5}$ of the whole length, and the large intestine, ending with the anus.

The movement of the food through the intestines is accomplished by a peculiar worm-like motion of the latter, resembling that of the stomach and called the peristaltic motion. It is produced by the involuntary muscles of the intestines, and effects both a forward movement of the food and a mixture of it with the various digestive fluids to whose action it is subjected.

Chief among these digestive fluids are the bile and the pancreatic juice.

The bile, or gall, of the herbivora is a dark yellowish-green liquid, secreted by the liver, the largest gland in the body, and, in most animals, stored up in the gall-bladder till it is needed.

The composition of the bile is very complex, and need not be taken up in detail here. It contains two characteristic coloring matters, *bilirubin* and *biliverdin*, but its most important and necessary ingredients are compounds of soda with certain organic acids, viz.: *glycocholic* and *taurocholic*, and in the hog *hyoglycocholic* acids. The soda of these compounds comes almost entirely from the salt (sodium chloride) of the food, while the same substance furnishes chlorine for the equally necessary muriatic acid of the gastric juice.

The chief action of the bile is on the fat of the food. A small portion seems to be decomposed by the soda salts of the bile, forming soluble soda salts of the fatty acids (soaps); but the main effect is to emulsify the fat, that is, to separate it into minute globules like the butter globules in milk, and to hold these globules suspended, so that the whole forms a thin fluid resembling milk and called an emulsion. This fluid can be taken up by the resorbent vessels of the intestines when the latter are wet with bile.

Besides its function of digesting the fats, the bile serves to hinder, to some extent, the decay of the easily decomposable albuminoids.

When bile is added to the contents of the stomach in the state in which they enter the intestines, the peptones which they contain, as well as the pepsin, are precipitated and the digestive process is stopped. A further addition of bile, however, redissolves the precipitate, but since the muriatic acid of the gastric juice is neutralized by the soda of the bile, the action of the pepsin is stopped. In the intestines, however, the latter is more than replaced by the ferment of the pancreatic juice.

The bile is secreted in very considerable quantity, but most of what is not used in digestion is taken up by the blood-vessels and resorbents of the intestines. The color of the solid excrements is due largely to portions of the bile that escape resorption.

The pancreatic juice, the secretion of the pancreas, or sweetbread, is a clear, viscid, colorless liquid, having a slightly salt taste and a distinctly alkaline reaction.

It contains at least three distinct ferments, viz.: a *diastase*, capable of converting starch into sugar; *trypsin*, which acts on the albuminoids; and a ferment which separates fats into glycerine and fatty acids.

By virtue of the first of these ferments, the starch of the food which is not acted on in the stomach is rapidly converted into sugar.

The trypsin of the pancreatic juice acts powerfully upon albuminoids in much the same way as the pepsin of the gastric juice, but with the differences that trypsin acts in alkaline or at most very weakly acid solution, and that the decomposition goes further.

Under the action of pepsin the albuminoids yield chiefly peptones, with small quantities of the well-known amides, leucin and tyrosin, while trypsin, on the contrary, decomposes the peptones at first formed, and produces abundant quantities of the amides just mentioned, at least in artificial digestion experiments.

The action of the pancreatic juice upon the fats is a two-fold one; it rapidly converts them into an exceedingly fine and permanent emulsion, and more slowly decomposes them into their constituents, glycerine and fatty acids.

It will thus be seen that the pancreatic juice is a most important secretion, acting, as it does, upon all three classes of nutrients and supplementing the saliva, the gastric juice, and the bile.

Intestinal fluid.—It is commonly stated that, in addition to the bile and pancreatic juice, the food is acted on by a third fluid secreted by numerous little glands, known as Lieberkühn's glands, in the mucous membrane of the intestines. The statements regarding the composition of this fluid and its action on the food are very conflicting, doubtless owing in part to the difficulty of obtaining it unmixed with the other digestive fluids, and there seems to be considerable doubt of its existence, which at any rate cannot be regarded as proven.

Recapitulation.—We see, then, that the whole process of digestion is simply a conversion of the solid matters of the food into forms which are soluble in water or in the digestive fluids and can therefore pass into the circulation. This is accomplished, in case of the albuminoids by the gastric juice in the stomach and the pancreatic juice in the intestines, in case of starch, etc., by the saliva and the pancreatic juice, and in case of the fats by the bile and pancreatic juice. In what part of the alimentary canal, or by what secretion, cellulose is digested, is not known. Possibly the pancreatic juice, which acts so powerfully on the other carbhydrates, is the agent of its solution, but this is only a conjecture.

The latest view regarding the digestion of cellulose is that it is not accomplished by any specific digestive fluid, but that in the extensive digestive canal of the herbivora it undergoes a sort of fermentation, caused by the innumerable bacteria and other low organisms there present, and yields marsh gas, carbonic acid, hydrogen, and various soluble products.

By the action of these various digestive fluids, the chyme which comes from the stomach is converted into a more or less thin, milky fluid, called *chyle*.

The ease of digestion depends on various circumstances.

Digestion is both a chemical and physical process, consisting of solution and chemical change of the nutrients by means of the digestive fluids, and the rapidity of this process depends, in general, upon the same conditions which determine that of similar processes outside the body. Hard and compact fodder is less easily digested than that which is soft and watery, other things being equal, simply because it is not so easily penetrated by the juices, and hence exposes less surface to their action, just as coarse salt dissolves more slowly than fine.

If the nutrients are shut up in insoluble envelopes, they are protected from the action of the juices. Thus, if we have starch in a cell whose walls are incrusted thickly with the indigestible (because insoluble) lignin, the starch may be, to a large extent, protected and escape digestion. So, too, if whole grain is fed and escapes mastication, the hard outer coats of the seed protect the interior, and the grain is frequently found with little alteration in the excrements.

In a chemical process, the proportions of the substances concerned are of the greatest importance.

So, too, in digestion, the proportions of albuminoids, carbhydrates, and fat, exercise an important influence on the digestibility of each of these groups, though exactly in what way we are ignorant.

That a moderate proportion of fat aids the digestion of the albuminoids in the stomach, has already been mentioned. Too great an amount of fat, on the contrary, hinders digestion.

If the fodder be poor in albuminoids and rich in starch, the latter may escape digestion in considerable quantities; and as it is of no value in the manure (since it only furnishes to the plant the elements of carbonic acid and water, with both of which it is richly supplied by the atmosphere) that which thus escapes is a dead loss, while if, on account of a too great proportion of albuminoids, a portion of these pass into the manure, they still are able to furnish the plant with the valuable element, nitrogen.

In a properly proportioned fodder, however, the quantity of really digestible matters that escapes digestion is comparatively small, although a *perfect* digestion of them is not to be expected. Small portions will escape digestion, either owing to their hardness and impermeability, or to their being protected by insoluble matters, or simply from the fact that they are not exposed for a sufficient time to the action of the digestive fluids.

This is shown by the fact that the ruminants, in which the process of digestion is long, extending through two or three days, are able to digest more of hard and difficultly soluble matters, especially of crude fibre, than other herbivora, in which the process is simpler and shorter, the horse, *e. g.*

§ 2. RESORPTION.

We have seen that the process of digestion is essentially a process of solution, the various nutrients of the food being altered into soluble forms and dissolved by the digestive fluids.

But the digested food, so long as it remains in the alimentary canal, is, to a certain extent, still outside the body; it has not yet been taken up into its vessels and become really a part of it. It must still be *resorbed* or taken up into the circulation by the resorbent vessels which line the stomach and intestines.

The Epithelium.—In all vertebrate animals, the whole surface of the intestines, from end to end, is covered with so-called epithelial cells, which are remarkably similar in all animals. These cells are roughly cylindrical, and are thickly crowded together, leaving no spaces between them. They are separated from each other by a cell wall, but are open toward the interior of the intestines, and also, according to some authorities, communicate on the other side with the lacteals.

The cells contain a soft mass of protoplasm, which, when resorption is not going on, bears on its intestinal surface minute upright fibres, which give the surface of the intestines a velvety appearance. During resorption, however, these fibres nearly disappear into the main part of the cell contents.

The Villi.—In the higher animals the extent of resorbing surface in the intestines is greatly increased by various folds and projections of its surface, of which the most important are the *villi*. These are little conical, round, or club-shaped protuberances of the inner surface of the intestines. They are covered, like all parts of the intestinal surface, with the epithelial cells just described, and underneath these there is said to be a fine membrane. Beneath this membrane there are found numerous minute capillary blood-vessels, a layer of smooth (involuntary) muscular fibres, and a net-work of nerves. All three layers follow the epithelium of the intestines in all its folds and projections, and thus in the villi take somewhat the shape of a glove-finger. In the centre of each of the villi ends a vessel called a lacteal, belonging to the lymphatic system.

Fig. 3 shows a longitudinal section of a villus, in which *a* represents the epithelial cells, *b* the capillary blood-vessels, *c* the layer of muscular fibres, and *d* the lacteal.

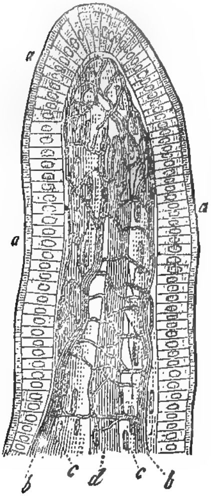

FIG. 3.—(Frey). Villus.

Lacteals and Blood-Vessels.—The lacteals unite into larger ones leading to the *mesenteric glands*, and after leaving these, finally join the *thoracic duct*, a large vessel leading forward (in man upward) and emptying into a vein in the left side near the collar-bone, called the *left subclavian vein*, near its entrance into the heart.

They derive their name from a milky-looking fluid with which they are filled during digestion, and which owes its appearance to the digested and emulsified fat of the food which has been resorbed from the chyle. At other times they contain a clear or opalescent liquid called lymph.

The capillaries of the intestines also unite into larger vessels, and finally into one, the *portal vein*, leading to the liver. (Compare fig. 4, p. 77.) There the blood which it carries is distributed through a second set of capillaries in that organ, and then reunited again into a single vein, the *hepatic vein*, leading almost directly to the heart.

Phenomena of Resorption.—As soon as the food passes from the stomach into the intestines, the resorbents of the latter begin their work, and the two processes of digestion and resorption go on simultaneously.

Our knowledge of the processes of resorption is not as full as might be wished. We know that liquids and soluble substances brought into the intestines, rapidly disappear from them. In some cases the substances thus resorbed are excreted unchanged; in others we are able to recognize the products of their decomposition without being able to say exactly where they are destroyed. Water introduced into the intestine disappears, and is excreted unchanged in the urine and perspiration; sugar, on the other hand, while it is rapidly resorbed, does not reappear as such, but speedily causes an increased excretion of carbonic acid through the lungs, showing that it has been oxidized in the body. It would seem that only soluble substances are resorbed, both from the fact that solutions are readily taken up and that the whole digestive process is directed toward solution of the solid ingredients of the food. The fats, however, form to a certain extent an exception. We have seen that in the digestive process they are simply emulsified, and only to a very small extent dissolved. After a meal containing much fat, the lacteals are found to be full of a fluid having a milky appearance which the microscope shows to be due to the presence of innumerable globules of fat, which have evidently been resorbed from the contents of the intestines, having passed through the epithelial cells.

Causes of Resorption.—It has been extensively taught that the phenomena of resorption are due chiefly to the action of the laws of the diffusion of liquids through membranes, aided by the pressure exerted on the contents of the intestines by the peristaltic motion.

It is well known that, if solutions of many substances be enclosed in some membrane, like bladder or parchment-paper, and the whole placed in water, the dissolved substance will diffuse through the membrane into the water until the solution is of equal strength on both sides of the membrane, and that, if the water be continually renewed, all the dissolved matter will finally be removed from the solution contained in the membrane. Substances which are capable of thus passing through a membrane are said to be diffusible.

In the body, according to this theory of resorption, the intestines constituted the enclosing membrane, the digestive fluids converted the nutrients into soluble and diffusible forms, while the blood and lymph of the capillaries and lacteals was the fluid into which diffusion took place. It was found that emulsified fats could, by slight pressure, be made to pass through a membrane previously moistened with bile, and on this fact was based the explanation of the resorption of fat, the pressure being supposed to be exerted by the peristaltic movements of the intestines, and the process of filtration to be aided by a peculiar structure of the villi which kept the lacteals in their centre under a less pressure than was exerted on the outside. In short, resorption was believed to consist in diffusion, combined with filtration under pressure.

This theory has been extensively held, but the best authorities now consider it entirely inadequate to explain the known facts of resorption.

As regards the resorption of fat, the simple fact that the villi are wanting in many of the lower animals, and that these animals nevertheless resorb fat, shows that the supposed peculiar structure of the villi is not essential to the process, and a more careful consideration of the anatomy of the intestinal surface shows that the filtration theory is untenable.

The whole of this surface is covered with the epithelial cells above described, so closely crowded together that any filtration must take place through the semi-fluid protoplasm of the cells. This protoplasm must behave under pressure essentially like a liquid, that is, it must exert an equal pressure upon all sides of an object enclosed in it; under these circumstances, while diffusion may take place, filtration is impossible. But if we admit the impossibility of filtration, the whole theory falls, for diffusion alone would, in many cases, produce results entirely different from those observed. For example, if water and alcohol be separated by a membrane having a greater attraction for water, the water passes through the membrane toward the alcohol faster than the latter passes in the opposite direction, but if alcohol, so diluted as not to injure the epithelium, be introduced into the intestines, it is rapidly resorbed into the blood, while no water passes from the latter into the intestines.

Moreover, while under normal conditions water is rapidly resorbed, simple irritation of the epithelial cells is sufficient to cause the motion to take place in the opposite direction, viz., from the blood into the intestines.

These and many other considerations force us to the belief that the epithelium of the intestines is the active agent in resorption, and that *resorption is a function of the living protoplasm of the epithelial cells.*

In what manner, or by virtue of what chemical and physical laws, the process takes place, we are ignorant; and until the relations and properties of protoplasm in general are much better known than at present, it must be regarded as a vain attempt to seek to discover them, nor, indeed, is it important for our present purpose that we should.

Course of the Nutrients after Resorption.—The substances taken up by the epithelial cells appear to pass from these into the lacteals. Their course from this point is not, in all cases, easily followed, on account of the rapid alteration which they undergo.

The fat seems to be carried exclusively by the lacteals, and to pass through the mesenteric glands and thoracic duct into the left subclavian vein, as already described. Other substances pass more or less completely into the blood. It will be remembered that the lacteals in the villi are surrounded by a net of capillary blood-vessels through which blood is continually passing, and there appears to be no reason why the easily diffusible substances of the lymph should not pass into the blood, especially since the latter, being continually renewed, would act like a large volume of fluid.

Probably, then, the products of the digestion of the carbhydrates—viz , sugar, lactic acid, etc.—pass, in large part, into the blood and through the portal vein, the capillaries of the liver, and the hepatic vein, to the heart. The same would be true of the amides formed by the action of the pancreatic juice and by decay from the albuminoids, and to a less degree of the peptones, while unaltered protein, if resorbed, would be largely retained in the contents of the lacteals, owing to its slow rate of diffusion.

All these statements are, however, to a certain extent, speculative. It is highly probable that the resorbed matters undergo chemical change in the act of resorption by the epithelial cells; at any rate they undergo such rapid alteration after resorption that only traces of most of them can be observed either in the lymph or in the blood of the portal vein.

The Fæces.—By the process of resorption the chyle, as it moves along through the intestines, is exhausted of its soluble parts and takes on a more and more solid consistency, and finally is voided from the body as the fæces.

The solid excrements consist of the indigestible part of the food, those digestible parts which for any reason may have escaped resorption, and small portions of the digestive fluids and of the worn-out mucous membrane of the intestines. In the herbivora they also generally contain all the phosphoric acid coming from the metamorphosis of the tissues of the body, while in the carnivora this substance is excreted in the urine. The color of the excrements, as already mentioned, is usually due to the portions of the bile which have escaped resorption; when much green fodder is eaten, its green coloring-matter (chlorophyl) passes unaltered into the fæces.

The composition of the solid excrements varies largely according to the feeding of the animal.

It is seldom possible to attain a *complete* digestion of all the nutrients of the food; a certain portion almost always escapes digestion, unless, perhaps, in the concentrated bye-fodders.

The undigested portion is generally larger when a rich food is given, *i. e.*, when we strive for a rapid production of organic substance, whether flesh, fat, or milk, than when the fodder is just sufficient to maintain the animal.

In the former case, too, the residues of digestive fluid and of worn-out intestinal membrane are greater, owing to the greater activity of these organs and the greater quantity of juices necessary to digest the richer and more abundant fodder, so that from fattening or milk cattle we get not only a utilization of fodder materials and conversion of them into valuable products, but an increase in the manurial value of the solid excrements, while in the case of animals on maintenance-fodder the manure is the only return for the fodder, and is of poorer quality than when richer food is given.

CHAPTER IV.

CIRCULATION, RESPIRATION, AND EXCRETION.

§ 1. CIRCULATION.

The Blood.—We have seen, in the preceding chapter, that the digested and resorbed nutrients of the food are carried more or less directly into the blood, and it is from this fluid that all parts of the body derive those substances necessary for their growth and the performance of their functions.

The blood of the higher animals is a thickish, somewhat viscid fluid, having a faint but peculiar odor, a slightly salt taste, and a color varying from bright to a dark red. It is somewhat heavier than water (sp. gr. 1.045—1.075), and contains about 21 per cent. of solid matters.

Under the microscope it is seen to consist of a clear fluid, the *plasma*, holding in suspension a vast number of small, round disks, the *corpuscles*.

The corpuscles are of two kinds. By far the most numerous are the red corpuscles. In man these are round like a coin but thicker at the edges than in the centre, and have a diameter of .0060—.0085 millimetres. Their number is enormous, being estimated at 4–5½ millions per cubic millimetre. The color and opacity of the blood are due to the corpuscles.

The corpuscles of each kind of animal are peculiar, both in shape and size, but their general characteristics are the same in all. Those of most mammals are smaller than those of man.

The corpuscles contain, as characteristic ingredients, two coloring-matters, known as *hæmoglobin* and *oxyhæmoglobin*, of each of which there appear to be several varieties in the blood of different animals.

Arterial blood contains only oxyhæmoglobin. This substance is a bright red, crystalline body, having pretty nearly the percentage composition of protein, but containing about 0.45 per cent. of iron. Its most remarkable property, however, is the readiness with which it parts with a portion of its oxygen and is converted into hæmoglobin. In the body this process takes place in the capillary blood-vessels, so that the blood as it returns from these to the heart (the venous blood) contains both oxyhæmoglobin and hæmoglobin. The latter is capable of the reverse change, and in the lungs takes up oxygen and is converted back into oxyhæmoglobin.

Besides these two coloring-matters, the corpuscles contain an albuminoid which is precipitated by concentrated salt solution, small quantities of two bodies known as *cholesterin* and *lecithin*, some other organic matters, and the usual ash ingredients, potash and phosphoric acid being especially abundant.

In addition to the red corpuscles the blood contains colorless corpuscles, differing in shape and appearance from the red and generally larger. They appear to be formed in the lymph before it joins the blood, but their exact function is not well ascertained. Their number is vastly less than that of the red, there being about one or two of the former to a thousand of the latter.

The plasma is a nearly transparent fluid, containing in solution a large part of the nutritive matters of the blood.

Of the albuminoids, it contains albumin, and blood-fibrin or at least one constituent of it; it also contains some fat, usually traces of sugar though never large quantities of it, and a considerable proportion of mineral matters, especially of soda salts and chlorides, besides minute traces of various other substances.

Coagulation.—So long as the blood remains in the vessels of the living body it continues fluid, even if its circulation be stopped, but when drawn from the body it coagulates after standing for a time, yielding a yellowish liquid, the *serum*, and blood-fibrin. At ordinary temperatures the change takes place rapidly, but only slowly at a low temperature; it is entirely hindered by addition to the blood of a strong solution of sulphate of soda, sulphate of magnesia, nitrate of soda, common salt, and other substances. Opinions differ as to the nature of the coagulation, but it is certain that the blood-fibrin does not exist as such in the blood but is formed from a substance called *fibrinogen*, contained in the plasma, and concerning which three facts may be considered as established: 1st. Fibrin is only formed in fluids which contain fibrinogen. 2d. A solution of fibrinogen alone yields no fibrin, and hence the action of some other body or bodies is requisite. 3d. This other body or bodies is yielded by the colorless corpuscles.

A. Schmidt, who has most fully investigated this subject, regards the substances coming from the colorless corpuscles as partaking of the nature of a ferment, and believes that they are not contained in the living blood but are formed, after the blood is drawn from the body, by the decomposition of the corpuscles. Whether this be true or not, there is no doubt that these corpuscles yield a substance capable of converting fibrinogen into fibrin.

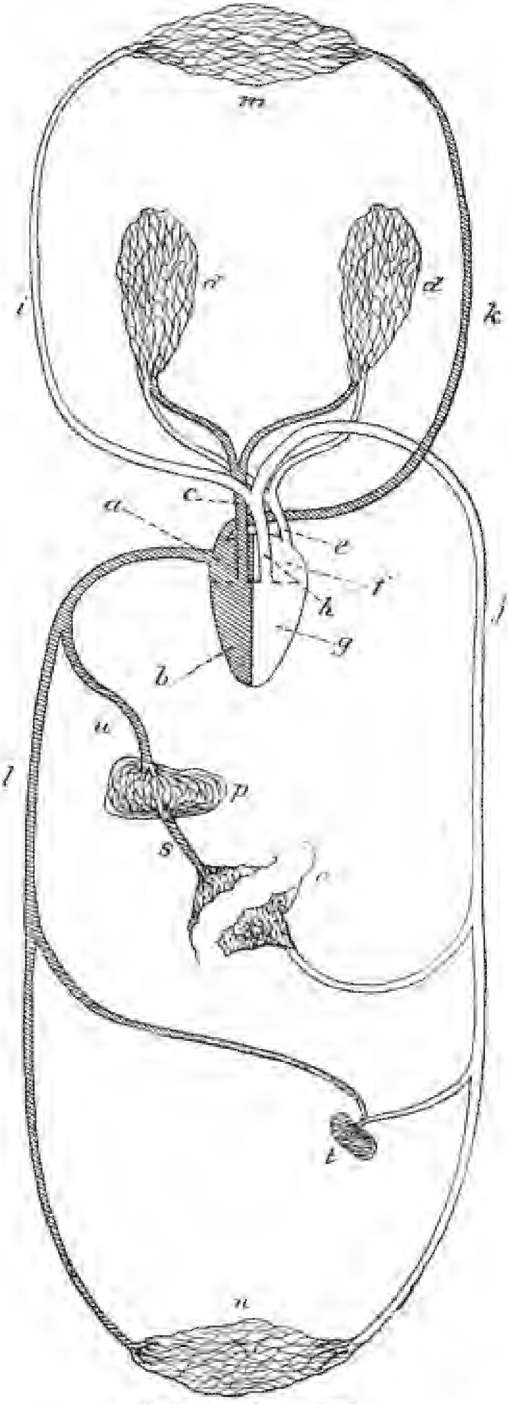

Fig. 4.—Plan of Circulation.

The Heart.—The movement of the blood through the body, in order that all organs may receive from it their necessary nourishment, is accomplished by the heart.

The heart is an irregularly conical-shaped organ, composed of involuntary muscles. It is situated in the anterior part of the chest, and hangs free in an envelope called the *pericardium*.

It is divided by an impervious partition into a right and left half, and each of these is subdivided by a cross-partition into two chambers, communicating with each other by a valve in the dividing wall. The upper and smaller of these divisions are known as the right and left *auricles*, and the lower and larger as the right and left *ventricles*. Into these divisions open several large blood-vessels, whose mouths are closed with valves so arranged that the blood can only flow *into* the auricles and *out of* the ventricles.

The blood returning from the extremities of the body to the heart enters first the right auricle, *a* (Fig. 4), through two large veins, the *vena cava anterior*, *k*, coming from the anterior, and the *vena cava posterior*, *l*, from the posterior part of the body. The auricle then contracts, and the blood, being prevented from returning into the blood-vessels by the valves at their mouths, is forced through the valve in the partition wall into the right ventricle, *b*. This, in its turn, contracts, and the blood, prevented as before by a valve from turning back in its course, is pressed out of the ventricle through the pulmonary artery, *c*, which divides into two branches leading to the right and left lungs, *d*, *d*. The opening of this blood-vessel, like that of the others, is provided with a valve, which prevents the return of the blood. The blood, after having been purified in the lungs, returns to the *left* auricle, *f*, through the pulmonary veins, represented by *e*.

The auricle then contracting, sends the blood into the left ventricle, *g*, which, in its turn, contracts powerfully and expels the blood into one large vessel, the *aorta*, *h*. The aorta, soon after leaving the heart, divides into two branches, the *anterior aorta*, *i*, leading to the fore part of the body, and the *posterior aorta*, *j*, supplying the abdominal cavity and the posterior part of the body.

These blood-vessels repeatedly subdivide and carry the blood to all parts of the body, to be brought back again to the right side of the heart and undergo the same process anew.

The sole cause of the motion of the blood is the powerful contraction of the muscles of the heart. This alternate contraction and relaxation constitutes the beating of the heart, and the sudden impulse thus given to the blood in the arteries causes the beating of the pulse.

The Arteries, which conduct the blood from the heart to the various organs of the body, are tubes with strong, elastic, and contractile walls, to withstand the force with which the blood is pressed into them by the heart. They originate in the aorta, *h* (Fig. 4), which receives the blood from the left ventricle, and as they extend farther and farther from the heart throw off branches to the various organs, become smaller and smaller, and finally end in the *capillaries*.

The Capillaries are exceedingly fine blood-vessels which penetrate all parts of the body and form the connecting link between the arteries and veins. Their walls are thin and delicate, and through them the nutritive matters of the blood diffuse out into the tissues to repair their waste, while the worn-out matters, at the same time, diffuse into the blood. Thus all parts of the body are kept continually bathed in a solution of nutritive matters.

In the capillaries, too, the oxygen which the blood has taken up in the lungs unites with some of the worn-out matters and burns them, producing the animal heat. This point will be spoken of more fully in the next section. In Fig. 4, *n* represents the capillaries of the posterior part of the body, *o* those of the stomach and intestines, *t* those of the kidneys, *p* those of the liver, and *m* those of the anterior part of the body. The capillaries gradually unite together into larger vessels, the veins, which convey the blood, no longer suited to nourish the body, back to the heart and lungs.

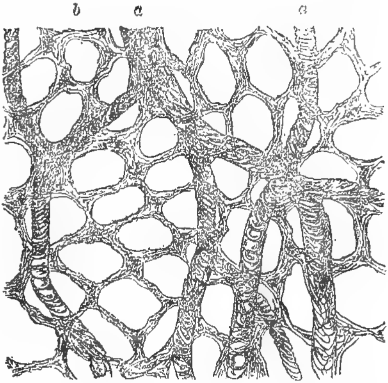

FIG. 5.—(Settegast.) Capillaries.

The Veins are tubular vessels somewhat similar to the arteries, but with weaker and non-elastic walls, the pressure of the blood on them being less, owing to the interposition of the capillaries between them and the arteries and to the fact that they are larger than the latter.

To prevent any possible flowing back of the blood, the veins are provided at intervals with valves which permit the blood to pass toward the heart but not in the opposite direction. The smaller veins unite to larger ones, and finally, as already described, empty their contents through two branches into the right auricle of the heart. From the capillaries of the intestines the blood carrying the resorbed nutrients passes through the *portal vein*, *s*, to the liver, *p*, there passes through another system of capillaries, and then rejoins the blood from the extremities through the *hepatic vein*, *u*. Into the branch, *k*, coming from the head and anterior part of the body, the nutrients which are resorbed by the lacteals are poured just before it enters the heart.

The passage of the blood from the left heart through the body and back to the right heart, is called the greater or *systemic* circulation; that from the right heart through the lungs to the left heart the *pulmonary* circulation.

The appearance of the blood in the veins and arteries is strikingly different. In the veins it has a dark, cherry-red color, but after it has passed through the lungs and is sent out by the heart into the arteries it has a bright, scarlet color. The former is called venous, the latter arterial blood. An exception to this rule, that the arteries carry bright-red blood and the veins dark, is found in the pulmonary circulation, where, of course, the vessels leading from the right heart to the lungs carry venous blood, and those leading from the lungs to the left heart, arterial. Nevertheless, the general nomenclature is adhered to, and the former are called arteries and the latter veins. Arteries conduct the blood *from* the heart, veins *toward* it.

§ 2. RESPIRATION.

Under respiration we here include not only the act of breathing, but all those chemical changes in the body of which that act is partly the cause and partly the consequence.

The Lungs.—The principal organs of respiration are the lungs, which, with the heart, occupy the cavity of the chest. This cavity is enclosed on the sides by the ribs, and is separated from the abdominal cavity, containing the digestive organs, by a strong, arched, muscular partition, the *diaphragm*. The diaphragm is convex toward the chest, and by its contraction and a simultaneous outward motion of the ribs, caused by muscles situated between them, the size of the chest cavity is enlarged, and air rushes into the lungs by virtue of the atmospheric pressure. This constitutes the movement of *inspiration*, or breathing in. The reverse motion, which immediately follows and expels a portion of the air, constitutes the movement of *expiration*, or breathing out.

The air enters the lungs through the trachea, or windpipe, from the mouth and nostrils. The trachea, after reaching the chest, divides into two branches, one leading to the right and the other to the left lung, and each branch subdivides again and again into a multitude of fine tubes, called bronchial tubes, each of which finally ends in an *ultimate lobule*, consisting of several minute *vesicles*. In Fig. 6, *c* represents the ultimate bronchial tube, *b b* the vesicles, and the whole mass of vesicles constitutes an ultimate lobule, *a*.

The vesicles and tubes have elastic walls and are surrounded by an elastic tissue, so that the whole lung constitutes a spongy mass which expands or contracts with the motions of the chest, causing the air to flow into and out of all parts of it. The vesicles are also surrounded by a net-work of extremely fine capillary blood-vessels, through which the blood sent to the lungs by the contraction of the right ventricle of the heart must pass, and the walls both of the capillaries and of the vesicles are very thin and are permeable to gases.

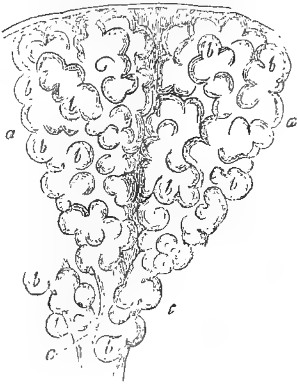

FIG. 6.—(Frey.) Lung Tissue.

Exchange of Gases in the Lungs.—The venous blood, as it comes to the lungs, is rich in carbonic acid, derived from the burning of waste products in the capillaries, and for the same reason is poor in oxygen; while the air in the vesicles of the lungs, on the contrary, is rich in oxygen and contains but little carbonic acid. Under these circumstances each gas moves from the place where it is most abundant to the place where there is a deficiency of it. The carbonic acid of the blood diffuses through the membrane of the blood-vessels into the air of the vesicles till the latter is as rich in that gas as the former, while the oxygen, at the same time, passes from the vesicles to the blood.

The carbonic acid is largely contained in the plasma of the blood, and simply diffuses into the air in the lung vesicles and is expelled in expiration, but for the taking up of oxygen there is a special provision in the coloring matters of the corpuscles. The venous blood contains both hæmoglobin and oxyhæmoglobin. When the blood passes through the lungs the hæmoglobin unites with the oxygen which diffuses into it, and when the aëration is properly performed is all converted into oxyhæmoglobin, which gives the arterial blood its bright-red color. The corpuscles thus act as vehicles for conveying oxygen from the lungs to the remotest regions of the body.

In the capillaries this oxygen is given up again in part, and hæmoglobin formed once more, giving to the venous blood its dark-red color.

If by any means respiration is stopped, the air in the lung vesicles speedily becomes so charged with carbonic acid and exhausted of oxygen that the exchange of gases with the blood can no longer go on; the carbonic acid is retained in the latter, the waste products of the tissues are not burned, and the animal's blood is poisoned—it is suffocated.

If its supply of air, however plentiful, contains more than a certain amount of carbonic acid, the removal of this gas from the blood is made incomplete or suspended entirely, and substantially the same results ensue, though more slowly.

Respiration through the Skin.—In addition to the exchange of gases between the air and the blood which goes on in the lungs, a similar process takes place, though to a smaller extent, through the skin.

The true skin, underlying the cuticle or scarf-skin, is penetrated by capillary blood-vessels, and in its passage through these capillaries the blood gives off some carbonic acid and takes up some oxygen by diffusion through the skin. The amounts thus given off and taken up are small compared with the corresponding amounts in the lungs, but they are still not inconsiderable. The skin likewise acts, by means of its sweat-glands, as a channel for the removal of water from the system. Large amounts of water are continually evaporating from the skin in the form of the "insensible perspiration," while under certain circumstances the excretion of water is so rapid as to give rise to the formation of visible drops.

The distribution of oxygen through the body is accomplished by means of the circulation. Each little corpuscle carries its load of oxygen from the lungs through the heart and arteries into the capillaries.

There, as we have seen, the substances formed in the minute cells of the tissue by the decomposition of their contents under the influence of the vital force, diffuse into the blood, and here they meet the oxygen contained in the corpuscles and unite with it—are burned, producing the *animal heat.* Innumerable intermediate products are formed in this process, but the final result is in all cases the same. All the non-nitrogenous substances yield carbonic acid and water; the nitrogenous ones the same substances, and in addition *urea*, the characteristic ingredient of the urine. Urea is a crystallizable body of comparatively simple composition, which, together with small amounts of other substances, contains all the nitrogen and part of the carbon and hydrogen of the albuminoids from which it is derived. In the urine of herbivorous animals it is, in part, replaced by *hippuric acid*. All these oxidations take place in the cells and capillaries of the body, and it is there, consequently, and not, as is sometimes stated, in the lungs, that the animal heat is produced.

The quantity of oxygen which passes into the blood is by no means determined by the depth and frequency of the inspirations, but by the *amount needed in the body;* that is, in the first place, by the rapidity of the decomposition of substances in the blood and tissues, as well as, in the second place, by the number and quality of the blood corpuscles.

In all parts of the living body a continual decomposition of its materials is going on, and all manifestations of life are intimately related to this metamorphosis of the materials of the living organism.

This decomposition, as has been already pointed out, consists, in the main, in a splitting up of complex compounds into simpler ones, accompanied by a liberation of energy, which manifests itself in various ways. The processes take place according to fixed laws and at first independently of oxygen, but the products of the decomposition unite with the oxygen of the blood and regulate the amount of this substance taken up in respiration. The splitting up of substances in the body to form simpler compounds must be regarded as the primary process and the taking up of oxygen as the secondary, although it was formerly believed that, inversely, the former was determined by the latter. If, by an increased supply of food or by violent muscular exertion, this splitting up of the materials of the body is increased and facilitated, then, secondarily, more oxygen will be taken up, in order that the resulting products may be oxidized.

Storing up of Oxygen.—We have hitherto, for convenience, spoken as if the oxygen taken up by the blood united at once in the capillaries with the products of tissue change.

Numerous experiments by Pettenkofer and Voit,* at Munich, and by Henneberg,† at the Weende Experiment Station, have, however, shown that the animal body has the power of storing up within itself a considerable amount of oxygen, and that some time may elapse after oxygen is taken up into the blood before it is excreted in combination with carbon and hydrogen. The following experiment by Pettenkofer and Voit, upon a healthy man on an average diet, will serve to illustrate the point. The experiment was divided into two parts, the time from 6 A.M. to 6 P.M. being designated as day and from 6 P.M. to 6 A.M. as night.

If from the amount of carbon, hydrogen, oxygen, and nitrogen, contained in the food eaten, we subtract the amounts excreted in organic combination in the solid and liquid excrements, and also the amounts laid up in the body in the form of fat, etc., the remainders will show how much of each element must have been burned to carbonic acid and water in the body. This known, we can easily calculate the amount of oxygen necessary for the process, and compare it with the amount actually taken up from the air, as determined by the method described in a subsequent chapter. In this experiment the following results were obtained:

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* Zeit. f. Biologie, II., 552.

† Neue Beiträge, etc., 1871, p. 245.

DAY.

	In food.	In excreta.	In fat formed in body.	Remain to be oxidized.	Oxygen required.
Carbon............	240.15	7.94	86.91	145.30	387.46
Hydrogen.........	195.40	1.71	13.53	180.16	1441.28
Oxygen...........	1455.79	8.64	13.10	1434.05	....
Nitrogen..........	10.12	10.12	0.00	0.00	....
					1828.74
Already present..................................					1434.05
Needed from without............................					394.69
Actually taken up from air..					234.70
Difference..................................					—159.99

NIGHT.

	In food.	In excreta.	In fat lost by body.	Remain to be oxidized.	Oxygen required.
Carbon............	75.35	19.16	47.11	103.30	275.50
Hydrogen.........	75.50	3.19	7.33	79.64	637.12
Oxygen...........	548.11	12.26	7.10	542.95	....
Nitrogen..........	7.24	7.24	0.00	0.00	....
					912.62
Already present..................................					542.95
Needed from without............................					369.67
Actually taken up from air........................					474.30
Difference..................................					+104.63
Difference for 24 hours........................					—55.36

In the night-half of the experiment, there was taken into the system through the lungs 104.63 grms. of oxygen more than was used during that time in oxidizing food substances and body-fat, while in the day-half of the experiment more oxygen was thus used than was supplied from without, the remainder (159.99 grms.) evidently being drawn from a supply previously laid up in the body.

In the earlier experiments of both Pettenkofer and Voit and Henneberg, the storing up of oxygen took place chiefly, as in this case, in the night, but further investigations showed that this was by no means always the case. It would seem, from these experiments, as if the healthy animal body were constantly either storing up or giving off oxygen, the two processes, as a rule, nearly balancing each other in the course of twenty-four hours, while complete equilibrium is seldom reached in that time. The significance of this fact we shall consider later.

Decompositions of the Nutrients in the Body.—*The albuminoids* of the food and tissues are believed to split up, by numerous intermediate steps, into *urea* and *fat.*[*] In the herbivora there are also formed varying quantities of *hippuric acid*, according to the fodder and the species of animal, but the latter always represents a far smaller part of the decomposed albuminoids than the urea, and often disappears almost completely from the list of the substances formed and excreted as the result of tissue-change.

The urea is rapidly taken up by the blood, separated from it again in the kidneys, and excreted in the urine; it can and ought never to be stored up in the healthy organism. In the normal blood and in the tissues are found only inconsiderable traces of it, although the total quantity which is formed daily in the body of a fattening steer may amount to a pound or more.

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[*] See the chapter on the "Formation of Fat."

The nitrogen contained in 100 parts of water-free protein can be separated from it in the form of 33.5 parts of urea. The remainder of the protein, 66.5 parts, after taking up and uniting with 12.3 parts of water, contains the elements for the formation of 51.4 parts of fat and 27.4 parts of carbonic acid.

The fat, whether formed from the albuminoids or contained as such in the food, is, according to circumstances, either deposited in the body of the animal, finds application in the production of milk, or undergoes a complete oxidation in the respiratory process, yielding carbonic acid and water. The fat producible from the albuminoids must always be added to that which is contained, ready formed, in the fodder and resorbed from the digestive apparatus, in estimating the results of a particular method of feeding. It is, however, to be observed that, according to the results of late researches, the fat formed in the body out of albuminoids appears to unite more readily with oxygen—that is, to burn easier—than the ready formed fat taken in the food, and this again easier than that which is already deposited in the fat-tissues.

The carbhydrates are represented in the body chiefly by sugar, all the other bodies of the group being converted into this substance during digestion, so far as they are not further decomposed. The food of all herbivorous animals contains large quantities of carbhydrates, an ox, for example, often resorbing into his blood from twelve to eighteen pounds of sugar in twenty-four hours, yet the blood, in its normal state, never contains more than minute traces of this substance, and it is never stored up as such in the body.

The cause of the comparatively small quantity of sugar found in the body, notwithstanding the large amounts taken into the blood, lies partly in the fact that the process of resorption is a gradual one, extending over a considerable time, the sugar, after it passes into the circulation, being oxidized with comparative rapidity, and partly, as it would appear, in the conversion of the resorbed sugar into an insoluble form by the liver.

Glycogen.—The liver, as long as it is in a normal state, contains a substance belonging to the carbhydrate group, and known as *glycogen*, in quantities varying according to the diet of the animal.

It may be extracted from the liver by hot water, and when purified forms a white, meal-like, amorphous powder, tasteless and odorless. In cold water it swells up, and on warming dissolves to an opalescent fluid. It is insoluble in alcohol and ether, and is colored dark-red by iodine. All those agents which convert starch and dextrine into sugar produce the same effect upon glycogen. It rotates the plane of polarized light strongly to the right, but does not reduce alkaline copper solution. It will thus be seen that it stands intermediate between starch and dextrine. Its composition is the same as that of starch.

Glycogenic Function of the Liver.—If the dead liver, after removal from the body, be washed out by water injected through the portal vein till all sugar is removed, and if then, after standing for a time, the washing be renewed, the first portions of water that pass contain sugar. The same process may be repeated several times. "If the liver of any animal be kept for a considerable time before cooking, the amount of sugar which accumulates in its substance is so large as to be easily detected by the taste. The liver is *decidedly sweet*."—(J. Le Conte.)

The source of the sugar in these cases is the glycogen of the liver, which, by some not well understood chemical action, is converted into sugar.

The same process takes place in the living body. The blood in the portal vein of flesh-fed animals contains no sugar, but the same blood in the hepatic vein, after having passed through the liver, contains a notable quantity of this substance, doubtless derived from the glycogen of the liver.

These facts were discovered by Claude Bernard in 1853, and are undisputed, but the source of the glycogen of the liver, and its physiological significance, are questions upon which there is a diversity of opinion. In what follows we shall endeavor to present in outline that view which seems, on the whole, most probable, without, however, treating the matter as one that is finally decided.

We have already called attention to the great quantity of sugar that may be taken into the circulation in the course of a few hours. This sugar is largely taken up by the capillaries of the stomach and intestines, and passes by the portal vein into the liver, while in the general circulation only traces of sugar are found.

Putting these facts together, the conclusion seems almost unavoidable that the liver has the power of converting sugar into the insoluble glycogen and storing it up, to be gradually reconverted into sugar as the needs of the organism demand. In other words, the glycogen of the liver is *a reserve of carbhydrates.*

The functions of the carbhydrates in the body are, as yet, but imperfectly understood, but there can be no doubt that they play an important part in the animal economy. According to some, the oxidation of these substances and of fat furnishes a large share of the muscular and other force exerted by the body. This does not appear to be fully established, but even if we do not hold this view, we shall see, in a subsequent chapter, that there is strong reason to believe that non-nitrogenous substances play an important part in the preparation of the muscles for the exertion of force, and that a constant supply of them in the blood is an important condition of healthy activity. On the other hand, it has been shown that a large quantity of sugar in the blood is very hurtful.

The office of the liver seems to be to arrest the sugar on its way from the portal capillaries and, by converting it into glycogen, to prevent an injurious accumulation of it in the blood, while the glycogen, by its gradual re-conversion into sugar, yields a continual supply of this substance.

Glycogen may be formed from Protein.—If a supply of sugar to the blood is important or necessary, we should expect to find some provision for it in those animals which take none in their food—*i. e.*, the *carnivora.*

This is, in fact, the case. The liver has the power to form glycogen from albuminoids, as is shown by the fact that that substance is formed in animals fed entirely on albuminoids. This being so, there is no evident reason why the same formation of glycogen from protein may not take place in all animals. Indeed some authorities hold that it does, and that all the albuminoids destroyed in the body are first decomposed in the liver into glycogen, and urea and similar products.

It will be shown in a subsequent chapter, however, that under some circumstances fat may be formed from the protein of the food and stored up in the body, and Voit and his followers hold that the first decomposition of protein in the body yields fat and not glycogen. However this may be, it is certain that *a part* of the protein may be used in fat formation, and as certain that part of it may also be used by the liver as a source of glycogen.

Protein as the Sole Source of Glycogen.—The views of the glycogenic function of the liver just stated, though widely accepted, are not undisputed. Many good authorities hold that under all circumstances protein is the source whence glycogen is formed. According to this view, the carbhydrates of the food are oxidized in place of the non-nitrogenous products of the decomposition of protein, and protect the latter, so that they are, in part at least, deposited in the liver in the form of glycogen, to be drawn on when the supply of carbhydrates in the food is insufficient.

That is, the liver has the power of preparing carbhydrate material from protein and storing it up in an insoluble form until such time as it is needed.

Which of these two theories is true, or whether the truth lies between the two, is as yet undecided, nor is a discussion of the comparative probability of the two views in place here.

Oxidations in the Body are Gradual.—In the foregoing paragraphs we have, for the sake of simplicity, spoken as if the processes of decomposition and oxidation were very simple and immediate—as if sugar were burned directly to carbonic acid and water, protein split up at once into fat and urea, etc. This is far from being the case. While the final result is *as if* the oxidations took place in the way spoken of, and while we are therefore justified in so speaking when we look at the chemical changes in the body as a whole, it must always be with the understanding that the changes which actually take place are very numerous and complicated, and that both their nature and location are largely hidden from us. The simple fact that oxygen, after it is taken into the blood, remains for a time in the system, suffices to show that the chemical phenomena in the body differ essentially from those outside it, and this is confirmed by the little we do know of the processes themselves and by the intermediate products, numbered by hundreds, which have been already discovered.

Fortunately, however, for the purposes of cattle-feeding we need only to know the final results of all these changes, and these we have indicated above, and shall presently consider more in detail.

§ 3. Excretion.

As the result of the continued decompositions and alterations going on in the body, we have a constant accumulation of carbonic acid, water, and urea and other nitrogenous products in the blood.

The carbonic acid and urea are poisonous if allowed to accumulate in the system, and the water would produce injurious effects by diluting the blood, and means are therefore provided for the removal of these substances from the body.

The Urine.—In its course through the posterior part of the body the blood passes through the kidneys, two bean-shaped organs, in which the urea and other nitrogenous substances coming from the decomposition of the protein of the body are removed from it. The blood also parts here with some of its water, and the excreted liquid, the urine, passes from the kidneys to the bladder and is thence expelled from the body at intervals.

Besides urea, the urine of the herbivora contains, as has been already noted, *hippuric acid*, in which form a varying but small proportion of nitrogen is excreted by these animals. In the carnivora its place is taken by *uric acid*, also a nitrogenous substance. The urine likewise contains traces of various other bodies, nitrogenous and non-nitrogenous, which, on account of their small quantity, are of no special importance here.

Excretion of Nitrogen.—In the nitrogenous substances of the urine is contained all the nitrogen of the albuminoids decomposed in the body. This is a most important fact, and one upon which a large part of the theory of feeding depends, and consequently it is desirable to examine somewhat in detail the evidence upon which it rests, particularly since its truth is still disputed by some authors.

The question is, whether the "sensible" excretions, that is, urine and dung, contain all the nitrogen which leaves the body, or whether any considerable portion of it is excreted in gaseous form from lungs and skin.

Since, unfortunately, we have no accurate means of determining directly whether free gaseous nitrogen is thus exhaled, we are obliged to approach the subject in an indirect way, and to determine whether, when no gain of flesh is made by the animal, all the nitrogen of the food reappears in the excreta.

The earlier experiments on this subject showed, almost without exception, a deficit of nitrogen in the excrements, seldom an excess. Boussingault found, with a horse, a deficit of 24 per cent. of the nitrogen of the food; with a milk-cow, 13 per cent.; with hogs, 37 and 55 per cent.; and with a turtle-dove, 34 and 36 per cent. Other observers also obtained a similar deficit, though quite variable in amount.

The extensive respiration experiments of Regnault and Reiset sometimes showed a slight excretion of gaseous nitrogen and sometimes a slight absorption of that substance, but the differences observed by them were far smaller than those obtained by most other observers.

Bidder and Schmidt[*] appear to have been the first to express the opinion that nitrogen leaves the body only in the visible excretions; but their experiments were too few in number to prove the point, and shortly afterward Bischoff[†] published the results of numerous experiments on dogs, in which he observed a considerable deficit, averaging 30 per cent. Hoppe-Seyler also found a deficit of 15 per cent. in an experiment in which a dog was fed for seven days exclusively on meat.

Voit's Experiments.—Karl Voit, in Munich, was the first to furnish decisive proof that the urine and dung are the sole channels by which nitrogen leaves the body, and that the nitrogen of the urine is an accurate measure of the amount of nitrogenous matters decomposed in the body.

He showed, in his "*Physiologisch-chemische Untersuchungen*," published in 1857, that the large deficit of nitrogen observed previously was due to faulty methods of experiment, and found in his own experiments either an equality between the nitrogen of food and excrements or differences which were explained very simply by the gain or loss of flesh by the animal under experiment.

Since that time a vast number of similar experiments, chiefly on dogs, have been made in the Physiological Institute at Munich by Voit, in conjunction with Bischoff and later with v. Pettenkofer, which have fully confirmed the results of the earlier ones and have been of the greatest service in elucidating the laws of the formation of flesh in the animal body. The following are a few of the results:[‡]

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[*] "Die Verdauungssäfte u. der Stoffwechsel," 1852.

[†] "Der Harnstoff als Mass des Stoffwechsels," 1853.

[‡] Wolff: "Ernährung Landw. Nutzthiere," p. 249.

Duration of experiments. Days.	Food.	NITROGEN.		DIFFERENCE.	
		In food. Grms.	In excrements. Grms.	Grms.	Per cent.
49	Meat.	2499.0	2525.6	+26.6	1.0
6		306.0	308.5	+2.5	0.7
9		459.0	460.7	+1.7	0.4
6		306.0	307.2	+1.2	0.4
12		612.0	611.9	−0.1	0.0
14		714.0	718.5	+4.5	0.6
23		1173.0	1176.9	+3.9	0.3
8		544.0	544.3	+0.3	0.1
20	Mixed Food.	340.0	335.2	−4.8	1.4
58		986.0	982.8	−3.2	0.3
3		153.0	152.6	−0.4	0.2
8		408.0	408.3	+0.3	0.07

That this equilibrium between the excreted and ingested nitrogen was not a chance occurrence in a single animal, is shown by the fact that it was confirmed in experiments on five different dogs.

Experiments on other animals have not been lacking. Ranke and Pettenkofer & Voit have shown that the same fact is true of men, and an interesting experiment was made by Voit on a pigeon, an animal with which Boussingault found a deficit of 34 and 36 per cent. Voit fed a full-grown pigeon for 124 days with peas, of which it consumed 3,132.4 grms. (dry weight), while its own weight rose from 371 grms. to 444 grms. The 3,132.4 grms. of peas contained 149.4 grms. of nitrogen, and in the excrements 145.9 grms. were recovered, showing a loss of 2.3 per cent. In this experiment the weight of the food was more than eight times that of the pigeon, and the amount of nitrogen in the food ten times that in the animal. Taking into account, also, the small weight of the animal and the duration of the experiment, the hypothesis of any appreciable excretion of gaseous nitrogen becomes untenable. The small deficit observed is largely explained by the fact that the animal gained 73 grms. during the experiment, and was found, when killed, to be rich in flesh.

Experiments on Domestic Animals.—The importance of Voit's observations for the founding of a rational theory of feeding, speedily led to experiments on agricultural animals, which showed that, as was to be expected, the same law holds good for them. A large number of experiments, in which various domestic animals have received a fodder which experience has shown to be sufficient to keep them in unaltered condition for long periods, have shown that under these circumstances all the nitrogen of the fodder reappears in the excrements.

Oxen.—The earliest observations were those of Henneberg, at the Weende Experiment Station, on oxen. His first experiments, in 1858 to 1859 and 1860 to 1861, agreed in the main with Voit's results, but, owing to the comparative imperfection of the experimental methods then available, considerable variations were found in particular cases. Further experiments, however, made in 1865,* with improved methods and apparatus, showed that these variations were due to experimental errors, and most abundantly confirmed Voit's observations, as the following results show:

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* "Neue Beiträge zur Begründung einer Rationellen Fütterung der Wiederkäuer," p. 380.

No. of Experiment.	Weight of animal. Lbs.	NITROGEN PER DAY.		DIFFERENCE.	
		In food. Grms.	In excrement. Grms.	Grms.	Per cent.
1........	1,403	135.5	135.0	−0.5	0.4
2........	"	131.0	132.0	+1.0	0.8
3........	"	131.0	127.5	−3.5	2.7
5........	1,529	161.5	167.5	+6.0	3.7
6........	"	160.0	156.5	−3.5	2.2

Grouven * also found approximately an equilibrium between the nitrogen of the food and of the excrements of oxen fed on clover hay. A ration of 14.3 lbs. of clover hay per day and head gave the following results:

Length of Experiment.	NITROGEN IN		DIFFERENCE.	
	Food. Grms.	Excrements. Grms.	Grms.	Per cent.
8 days.......	1,087.79	1,153.67	+65.88	6.0
10 days.......	1,506.42	1,463.63	−42.79	2.8

Milk cows.—Experiments on five different cows in three different places—viz., in Munich, by Voit,† at the Experiment Station at Möckern, by G. Kühn,‡ and at the Hohenheim Experiment Station, by E. v. Wolff §—

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* Zweiter Bericht über die Versuchs-Station Salzmünde, 1864, p. 122.

† Zeitschrift für Biologie, 1869, p. 118.

‡ Landw. Versuchs-Stationen, XII., 450.

§ Die Versuchsstation Hohenheim, 1870, p. 49.

have shown that the visible excrements of these animals also contain all the nitrogen which leaves the body.

The following table gives a resumé of all the results, expressed in grammes per day and head:

Place.	Length of feeding.	Nitrogen in		Difference.	
		Food. Grms.	Excrements.* Grms.	Grms.	Per cent.
Munich....	6 days.	241.5	238.53	−2.97	1.2
Möckern...	20 to 25 days.	120.5	122.0	+1.5	1.2
"	"	121.0	117.5	−3.5	2.9
"	"	117.4	113.1	−4.3	3.6
"	"	114.5	120.0	+5.5	4.8
"	"	114.8	108.4	−6.4	5.6
"	"	121.4	113.2	−8.2	6.7
Hohenheim	Nearly 6 weeks.	165.2	164.5	−0.7	0.4
"	"	169.1	169.8	+0.7	0.4

Sheep.—In case of sheep, we have to take into account, besides the excrements, the growth of the wool. The following results, selected from those obtained by Märcker and E. Schulze † in a large number of experiments at the Weende Experiment Station, show that when this is done the same law holds with sheep as with other animals.

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* Including the milk.

† Jour. f. Landw., 1870, p. 301.

No. of Animal.	Live weight. Lbs.	Nitrogen of fodder per day. Grms.	Nitrogen excreted per day. Grms.	DIFFERENCE.	
				Grms.	Per cent.
III..........	94.7	17.81	16.93	−0.88	4.9
I............	104.0	17.26	16.12	−1.14	6.6
III. & IV. (av)	100.4	14.40	14.16	−0.24	1.6
I. & II. "	122.1	16.34	17.46	+1.12	6.8
III. & IV. "	103.6	14.76	15.15	+0.39	2.6
II...........	135.5	25.37	25.20	−0.17	0.7
III..........	109.5	19.52	19.85	+0.33	1.7

Goats.—The following experiments, made by Stohmann * at the Halle Experiment Station, show that in the goat also the excretion of nitrogen takes place in the visible excreta, and that no considerable excretion of gaseous nitrogen can occur:

No. of the Animal.	Live weight. Lbs.	NITROGEN PER DAY.		DIFFERENCE.	
		In fodder. Grms.	In excrements and milk. Grms.	Grms.	Per cent.
I.	81.1	23.3	23.0	−0.3	1.3
II........	63.5	23.0	22.2	−0.8	3.5
I.	81.4	21.1	21.5	+0.4	1.9
II........	62.2	21.1	21.4	+0.3	1.4
I.	85.3	23.9	23.5	−0.4	1.9
II........	66.0	23.7	23.6	−0.1	0.5
I.	83.4	24.6	24.3	−0.3	1.4

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* Zeitschrift für Biologie, 1870, p. 204.

For the sake of brevity, no description of the fodder has been given in any of the above experiments. It is sufficient to say that it was found by experience to be just sufficient to maintain the animals, and that the latter did not appreciably gain or lose during the trials. The duration of the feeding, when given, refers in most cases to the total length of time during which the fodder was used; the actual investigation of dung and urine usually extended over 7 to 10 days.

Investigations of the Respiratory Products.—The experiments which we have already described have shown conclusively that no appreciable excretion of nitrogen takes place through lungs and skin, and direct investigations of the respiratory products have only confirmed this fact. It is true that we have no means of accurately determining how much free nitrogen is exhaled, but any ammonia that may pass off in this way can be very exactly determined. Such experiments have been executed, and have all shown that only minute quantities of this gas are excreted. Thus Grouven,* in experiments on twenty-nine different individuals, obtained the following amounts of ammonia per 1,000 lbs. live weight per day:

	Grms.		Grms.
Man	0.287–0.510	Sheep	0.340–0.585
Boy	0.457–0.541	Dog	0.663–1.350
Ox	0.206–0.614	Horse	0.259
Cow	0.174–0.392	Ass	0.673
Calf	0.774	Goat	0.585
Hog	0.921		

Other observers have obtained equally small and unimportant amounts.

Quite recently, Seegen and Nowak,† in Vienna, by a peculiar arrangement of the respiration apparatus, claim to have shown an exhalation of free gaseous nitrogen by various animals; but the method adopted by them demands such extraordinarily accurate analyses that the results obtained can as well be attributed to analytical errors as to an actual excretion of free nitrogen.

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* Zweiter Salzmünder Bericht, 1864, p. 235.

† Biedermann's Central-Blatt, 1879, p. 593.

Determination of Gain or Loss of Flesh.—In the foregoing paragraphs we have presented, somewhat at length, some of the evidence which shows that nitrogen is excreted to any considerable extent only in the visible ejecta. This evidence could have been greatly amplified were it necessary, but enough has been given to prove the point in question.

The value of this knowledge lies in the fact that by virtue of it we can determine easily and exactly whether an animal is gaining or losing nitrogenous constituents, *i.e.*, flesh. We need only to compare the amount of nitrogen in the digested portion of the daily fodder of the animal with that daily excreted in its urine; or, more simply still, to compare the total amount of nitrogen in the fodder with that of all the sensible excrements, both urine and dung. If the amount in the fodder is the greater, the difference evidently must be still retained in the body as flesh. If, on the contrary, the amount is greater in the excrements, it shows as conclusively that more albuminoids have been decomposed than have been supplied, and that the animal is losing flesh.

Furthermore, since the albuminoids contain on an average 16 per cent. of nitrogen, we can, by multiplying the difference found by the factor 6.25, as explained on page 17, calculate the weight of albuminoids corresponding to the observed difference of nitrogen, and thus tell exactly *how much* flesh has been gained or lost. If the amount of nitrogen found in the excrements is the same as that given in the fodder, it shows, of course, that neither a gain nor a loss has taken place.

In a subsequent chapter we shall see that all our knowledge of the laws of the formation of flesh has been obtained in this way, and that consequently the truth of those laws depends on the truth of the view that the urinary nitrogen is a measure of the amount of protein decomposed in the body.

Excretion of Carbon.—The carbon of the organic matters destroyed in the body is excreted in two ways.

Part of it leaves the body in the various urinary products, but by far the larger portion is excreted as carbonic acid through lungs and skin, as already described, so that an investigation into the gain or loss of carbon by the animal body requires a determination of the gaseous excreta.

Excretion of Hydrogen.—A portion of the hydrogen of the tissues is also excreted through the kidneys, a little of it in combination with carbon, nitrogen, and oxygen, in the urea, etc., but most of it in the form of water.

Considerable quantities of water are also excreted through the lungs, as is made evident by the visible condensation of the moisture of the breath on a cold day, and likewise through the skin.

CHAPTER V.

METHODS OF INVESTIGATION.

THE practical result of a particular method of feeding shows itself, if we neglect for the moment the production of milk and wool, in a gain of flesh or fat in the body of the animal and in the production of work. We have, then, to consider more minutely the various circumstances which are favorable or unfavorable to the production of fat or flesh, and by which a greater or less amount of useful exertion is made possible to the animal.

But before so doing, it will be profitable to cast a brief glance upon the methods used in investigations on these subjects—on the ways and means by whose help our knowledge, especially of the laws of flesh-production, has of late been essentially increased and made clearer.

§ 1. DETERMINATION OF DIGESTIBILITY.

Digestion Experiments.—While the pure nutrients are theoretically capable of being wholly dissolved and resorbed in the digestive apparatus, yet in practice they are so enclosed in or impregnated by indigestible matters, which protect them from the action of the digestive fluids, or the effect of the latter is so modified by the presence of several nutrients at once, that a greater or less portion escapes digestion and is excreted in the dung.

To determine the digestibility of a feeding-stuff, both the latter and the dung of the animal are carefully weighed, and analyzed in exactly the same way. The absolute quantity of each nutrient which enters and leaves the body being thus known, the difference between the total amount of dry matter in fodder and dung gives the total amount of matter digested, and the difference in the amount of any particular constituent, *e. g.*, crude fiber, shows how much of that constituent has been digested.

It is a matter of course that the greatest care must be exercised, both in the weighing off and portioning out of the fodder, in the collection of the excrement, and in the preparation of a correct sample for chemical analysis.

In fact, a high degree of accuracy has been reached in such "digestion experiments" by the help of various apparatus, stall fittings, and other arrangements, as may be seen from the results of control experiments, especially when the animal is of a kind favorable to the attainment of accurate results. The latter is generally the case with the smaller animals, particularly with sheep.

The Time occupied in Digestion in the ruminants is comparatively long; it has been found by numerous observations, made in various ways with the same result, that after a sudden alteration of the feeding, the remnants of the former fodder are still recognizable in the excrements for as much as five days. Accordingly, in all digestion experiments, the fodder whose digestibility is to be determined must be fed for a period of several days before the excrement can be safely considered as corresponding to the fodder and before a sample can be taken for analysis. This preparatory period must, of course, be long enough to insure the complete elimination of the remnants of the previous fodder; generally it is extended to at least seven days.

This preparatory period is the more important since the fodder undergoes a much more intimate mixture in the long and complex digestive apparatus of the ruminants than in the shorter and simpler one of the carnivora or of man. In the latter it is often possible to distinguish the excrement coming from the new fodder by its appearance simply, and if a little colored fruit be eaten, it frequently forms a sharp line of division between the two.

The process of digestion in the horse and hog is, indeed, more rapid than in the ruminants; but, nevertheless, in experiments on these animals, a similar preparatory period is observed, to insure entire accuracy.

A Source of Error in Digestion Experiments.—The amount of solid matter digested must be equal *at least* to the difference between fodder and excrement; it is, in fact, slightly greater, for the reason that the dry matter of the excrement is somewhat increased by the addition of certain products of the intestines themselves, and especially of portions of the bile which escape resorption, so that the apparent digestibility of the fodder is decreased by that amount.

Some idea of the amount of *nitrogenous* substance thus excreted, and the consequent error in the determination of the digestibility of the albuminoids, may be obtained by determining the nitrogen in the ethereal and alcoholic extracts of the excrement, and also the sulphur in organic combination contained in the aqueous extract. The constituents of the bile are largely soluble in alcohol and ether, while the albuminoids are not; of the bile-constituents not thus soluble only the taurin needs to be considered, and this is soluble in water and distinguished by a very large content of sulphur (25.6 per cent.), while its nitrogen amounts to 11.2 per cent. In this way it is not difficult to find the greatest quantity of nitrogen which may possibly have come from unresorbed biliary substances.

Some experiments made in Weende by E. Schulze and M. Märcker * showed that this nitrogen, in the case of sheep fed exclusively on hay, constituted only about 4 per cent. of the total nitrogen of the excrement and equalled only about 2 per cent. of that of the fodder, so that it could not cause a very considerable error in the determination of the digestibility. In the excrement of swine, which generally consume easily-digestible fodder and therefore excrete comparatively little solid matter in their dung, the quantity of biliary products is indeed relatively greater, and their nitrogen amounts, according to experiments in Hohenheim and in Kuschen, to one-fifth or even one-fourth of the total nitrogen of the excrement, but, owing to the high digestibility of their ordinary fodder, equals only 3 to 6 per cent. of the nitrogen of the latter.

These biliary and other products, then, can seriously impair the determination of the digestibility of the albuminoids only when the fodder is extraordinarily poor in nitrogen. For example, it was observed by Grouven, at the Salzmünde Experiment Station, that full-grown oxen on almost "starvation fodder," amounting to only 5 to 9 lbs. of rye straw, together with non-nitrogenous materials, per day, sometimes excreted more nitrogen in their dung than they received in their fodder.

It is therefore difficult to arrive at even tolerably accurate results regarding the digestibility of the protein in substances so poor in nitrogen as the straw of the cereals, when these are fed alone; but with even an approximately sufficient fodder, the influence of the biliary products, etc., is not at all considerable and becomes less the more nitrogenous the fodder, since it has been found, at least in the

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* Jour. f. Landw., 1871, p. 49.

Hohenheim experiments on swine, that the absolute quantity of these products in the excrement is no greater with a rich than with a poor fodder.

Digestibility of Fat.—The determinations of the digestibility of *fat* hitherto made in digestion experiments are much less exact than those of the digestibility of albuminoids. Most of the biliary products are soluble in ether, and as the ordinary fodder of domestic animals contains but a small quantity of fat, by the addition of these products to the actual fat contained in the excrement the apparent digestibility of the fat must evidently be very considerably decreased, and the more so the less of it is contained in the fodder.

In some experiments by E. v. Wolff, at Hohenheim,* on swine, the animals were fed exclusively with potatoes—a fodder containing but little fat—and the absolute quantity of crude fat (or, more correctly, of matter soluble in ether) in the excrement was considerably greater than that contained in the fodder, amounting to 9.48 grms., and 10.95 grms. per day and head, against 4.27 grms. and 4.91 grms. in the fodder.

But, notwithstanding this source of error, digestion experiments yield results for fat which, although by no means absolutely correct, are yet, to a certain extent, comparable, and have a certain worth in estimating the value of a fodder, though it must always be borne in mind that they are too low, and the more so the poorer the fodder is in fat. We have already learned that the results obtained in fodder analysis are only approximate. They do not represent pure substances, but serve, when all analyses are carried out in the same way, to compare different fodders with each other. The same is of course true of the analysis of the excrement, which is purposely made after the same method. Remembering these facts, we comprehend that the determinations of digestibility are likewise only approximations. More accurate results are greatly to be desired, but at present we have no means of obtaining them and must be content with our present methods, which, though confessedly imperfect, have yet been of the greatest service in placing the practice of cattle-feeding on a rational basis. We can understand, then, that the presence of these biliary and other products in the excrement is not so great a source of inaccuracy as it might at first thought seem, since their quantity is relatively small and is comparatively constant in the same animal, so that the results of digestion experiments are fairly comparable. At any rate, we may be sure that, if we base our calculations of the amount of fodder to be given for any particular purpose on results obtained by the above methods, the animals will not get *less* than the calculated amount of nutrients, though they may receive slightly more.

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* Landw. Jahrbücher, VIII., I. Supplement, p. 202.

§ 2. Determination of the Nutritive Effect of a Ration.

Production of Flesh.—The method of determining the gain or loss of flesh in an animal, which has been already indicated, is based on the well-established fact that the nitrogen of the urine is an accurate measure of the amount of protein decomposed in the body.

If in a digestion experiment, carried out as described in § 1, the urine of the animal be also accurately collected and measured, and the quantity of nitrogen which it contains determined, we have all the data necessary to determine the gain or loss of flesh.

From the determinations of the digestibility of the fodder we know how much nitrogen has entered into the system, while the urinary nitrogen tells us how much has left it; the difference between the two, of course, is the gain or loss of nitrogen by the body, and since the albuminoids contain, on an average, 16 per cent. of nitrogen, this quantity, multiplied by 6.25, gives the gain or loss of dry protein. If it is desired to know the amount of fresh flesh, with its normal content of water and ash, which has been gained or lost, this also can be calculated from the average composition of the latter. Voit,* in all his experiments, reckons, on the basis of his own and other analyses, that fresh flesh, free from fat, has the following composition:

Water	75.9	per cent.
Ash	1.3	"
Dry matter	22.8	"
	100.0	
Nitrogen	3.4	"

Other observers have obtained results differing slightly from this, but not sufficiently to be of serious consequence, and since so many experiments by Voit and others are calculated on this basis, it will be convenient to follow the example of this eminent investigator. Assuming, then, that fresh, fat-free flesh contains 3.4 per cent. of nitrogen, we have only to multiply the gain or loss of nitrogen observed in our experiment by 29.4 (3.4 per cent. × 29.4 = 100 per cent.) to learn how much flesh our animal has laid on or destroyed, while similar calculations on the total urinary nitrogen will inform us of the total amounts, respectively, of protein or of flesh decomposed in the vital processes.

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* "Ernährung des Fleischfressers," 1860, p. 304, and Zeitschrift für Biologie, 1866, p. 468.

A preparatory period of feeding is, of course, necessary, as explained in the previous section, and this must be long enough to allow the body to come into equilibrium with the food, so that the effects of the latter may have fully developed themselves. The experiment proper must also extend over a sufficient time to give a fair average. At least twenty-four hours is necessary for this, but better results are obtained when the experiment covers several days.

Finally, it should be remembered that the results obtained show, in the first place, only the gain or loss of *nitrogen*, and that the factors used for converting this into protein or flesh are average numbers only, and that, while they are nearly enough true for practical purposes, they are not absolutely accurate in all cases.

Production of Fat.—As the production of flesh is estimated by a comparison of the receipts and expenditures of nitrogen by the body, so the production of fat is estimated by the gain or loss of carbon.

For this purpose it is necessary to take into account the gaseous products of respiration and perspiration, since the larger part of the carbon excreted leaves the body through these channels.

These products can only be estimated with accuracy by means of a special apparatus, first constructed in a practical form by Pettenkofer, in Munich, and now widely used under the name of "Pettenkofer's Respiration Apparatus."

The Respiration Apparatus.—The principles of this most important apparatus are well illustrated in an ordinary stove, in which the gases coming from the fire may represent those coming from the lungs of the animal.

As long as the chimney draws, no smoke escapes from the doors and draughts of the stove, but, on the contrary, the air presses from all sides into the stove, to pass out through the chimney.

If, in the pipe conducting the smoke from the stove to the chimney, an exact measurement of the volume of air passing were possible, and if, also, the composition of the air entering the stove and of that passing out could be exactly determined in an aliquot part of it, we should have all the factors needed in order to determine what had been added to the air that entered the stove by the fire inside it.

In the respiration apparatus the place of the stove is taken by a small room, constructed of boiler-iron, serving to contain the subject of the experiment. This room has windows, cemented as air-tight as possible into its sides, and a door, provided with slides through which the outside air has unhindered entrance.

The place of the chimney is taken by large air-pumps which are kept in uniform motion at any required velocity by powerful clock-work, which is wound up continually by a small steam-engine. In some cases this arrangement of pumps has been replaced by a rotary blower.

The air which is pumped out of the saloon is accurately measured by means of a large gas-meter, and in order to obtain an aliquot part of this air, and at the same time to analyze the air as it enters the saloon, small mercury pumps are provided, which withdraw uniformly a certain portion of air from that leaving the saloon and also from the air just before entering it. These portions of air are accurately measured by smaller meters, and their content of water and carbonic acid determined by absorption of the water by sulphuric acid and of the carbonic acid by baryta water.

The difference in water and carbonic acid between the air as it enters and as it leaves the saloon, calculated on the whole volume of air passing through it, gives the quantity added in the apparatus, *i. e.*, expired by the animal. It will be seen that the above-described apparatus is so arranged that the animal or man experimented upon is under entirely normal circumstances, *i. e.*, under the same atmospheric pressure and in an equally pure atmosphere as in a stall or ordinary room. This is a great advantage. because only in this way can the experiment be carried on as long as is desirable, and results obtained which are reliable and correspond to natural conditions.

By the use of the respiration apparatus, in connection with analyses and weighings of food, drink, dung, and urine, we are able to determine *all* the materials put into and removed from the body, and thus to know the exact effect of any given ration.

The calculation of the gain or loss of flesh has already been explained. By determining the amount of carbon contained in the carbonic acid excreted through the lungs and skin and in the urea, etc., excreted by the kidneys, and comparing it with the amount contained in the digested portion of the food, we can find whether the animal is gaining or losing carbon in the same manner as we can determine whether it is gaining or losing nitrogen. If the excreted carbon is less than that contained in the food, the difference must have been retained in the body; if greater, the excess must have come from the tissues of the body. The gain or loss of carbon, however, may have been in one or both of two forms: viz., fat or albuminoids.

If the comparison of the nitrogen in fodder and excrements shows that the body has neither gained nor lost albuminoids, then the carbon gained or lost was all in the form of fat, since the other non-nitrogenous substances in the body are so small in amount that they can be neglected. But every 100 parts of fat contains, on an average (p. 12), 76.5 parts of carbon, and therefore every 76.5 parts of carbon shown by the experiment to have been gained or lost represents 100 parts of fat, or one part of carbon corresponds to 1.3 parts of fat. The method of calculation is exactly similar to that used in calculating the gain or loss of albuminoids from that of nitrogen.

The calculation is essentially the same if a gain or loss of albuminoids has taken place, except that the amount of carbon contained in the latter must be deducted from or added to, as the case may be, that found by experiment before multiplying by the factor 1.3. An example will render this clearer.

In an experiment made at the Weende Experiment Station on sheep, the animals received per day and head 1,216 grammes * of hay, together with the necessary amount of water. In fodder and excrements were found the following amounts of carbon and nitrogen :

	Carbon. Grms.	Nitrogen. Grms.
IN FODDER—		
Hay	460.1	18.1
Water	0.1	.0
	460.2	18.1
IN EXCREMENTS—		
Dung	202.5	8.45
Urine	23.2	7.65
Expired air	213.8	....
	439.5	16.10
Retained in body	20.7	2.00

Taking first the gain of nitrogen, we find that

2 grms. × 6.25 = 12.50 grms. of protein.
2 " × 29.4 = 58.80 " " flesh.

and, therefore, that the animal had gained 58.8 grms. of flesh in twenty-four hours.

Taking next the gain of carbon, we have to consider how much of it is due to the gain of flesh, and how much to a deposition of fat. The albuminoids contain on an average (p. 17) 53 per cent. of carbon, and hence the 12.5 grms. of albuminoids gained in this experiment contained 6.6 grms. of this element. Out of the total gain of 20.7

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* One gramme = 15.43 grains; 1,000 grammes = 1 kilogramme = about 2.2 lbs.

grms. of carbon, then, 6.6 grms. were contained in the flesh laid on, leaving 14.1 grms., which must have been gained as fat. But, as we have seen, one part of carbon is equivalent to 1.3 parts of fat, and hence we have—

$$14.0 \times 1.3 = 18.2 \text{ grms.},$$

the amount of fat gained.

So, then, the result of the ration of 1,216 grms. of hay per day was, in this particular case, a gain by the animal of 12.5 grms. of albuminoids and 18.2 grms. of fat in twenty-four hours.

By a similar process the gain or loss of *water* by the body can be determined, and thus the total gain or loss, as shown by the live-weight of the animal from day to day, can be analyzed, and we are enabled to say how much of the gain which may be observed is the valuable flesh or fat, and how much is due simply to a greater or less quantity of water in the tissues, or of food and drink in the intestines.

The following table (p. 116) gives the detailed results of the above experiment in the form of a balance-sheet, and will give some idea of the care and labor with which such investigations are conducted.

Any loss by the body is, of course, placed on the "consumption" side of the account, and any gain on the "production" side.

The Live-weight alone, although very valuable for many purposes, gives but a very imperfect idea of the effect of a ration. The live-weight of an animal includes not only the solid matter of its tissues, but also water, the food eaten, and the dung and urine contained in the rectum and bladder; so that an increase of the live-weight by forty or fifty pounds is capable of many interpretations.

	Dry Matter.	Water.	Ash.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.
Consumption.	Grms.	Grms.	Grms.	Grms.	Grms.	Grms.	Grms.
2936.5 FOOD AND DRINK:							
1216.0 Hay..............	997.4	218.6	67.9	460.1	85.8	18.1	584.0
6.0 Salt................	5.7	0.3	5.7	......	0.03	......	0.27
1714.5 Well-water	1.8	1712.7	1.6	0.1	190.3	......	1522.5
0.8 LOSS BY BODY............	0.8	......	0.8	......	......	......	....
587.6 OXYGEN FROM AIR.........	......	.....	......	......	......	......	587.6
3524.9			76.0	460.2	276.2	18.1	2694.4
Production.							
1814.5 EXCREMENTS:							
1257.0 Dung..............	424.9	832.1	44.0	202.5	117.5	8.45	884.6
557.5 Urine..............	79.7	477.8	31.1	23.2	55.5	7.65	439.9
1640.1 RESPIRATORY PRODUCTS:							
780.0 Carbonic acid	......	......	......	212.7	....	......	567.3
1.5 Marsh gas..........	......	......	......	1.1	0.4	......	....
858.6 Water.............	......	858.6	......	......	95.4	......	763.2
70.3 GAIN BY BODY:							
9.5 Wool (includ. fat, etc.)	7.4	2.1	0.9	3.5	0.7	0.75	3.7
7.8 Protein.............	7.8	......	......	4.1	0.6	1.25	1.9
17.1 Fat.................	17.1	......	......	13.1	2.1	......	1.9
35.9 Water..............	......	35.9	......	......	4.0	......	31.9
3524.9			76.0	460.2	276.2	18.1	2694.4

It may indicate a gain of flesh or fat, or both, or it may result simply from an increase of the water content of the tissues, or from an increased amount of food, water or dung in the intestines. The stomach alone of the ox will hold 100 to 150 lbs. of water. The excretion of dung, too, is more or less irregular, especially for the first week or two on a new ration.

“Grouven found in many of his feeding experiments that during the first week the amount of dung excreted was often as much as twenty pounds too great or too small.”

To get the most correct results from live-weight, the animals should be weighed always at the same time in the day, either before or after eating, but always under the same circumstances, so far as possible. With all precautions, however, the live-weight of a thousand-pound animal may vary as much as 50 lbs. daily.

Stohmann gives the following example:

An ox	weighed,	May 23	1298.3	lbs.*
“	“	“ 24	1242.4	“
“	“	“ 30	1269.8	“
“	“	“ 31	1288.3	“
“	“	June 3	1271.1	“
“	“	“ 4	1210.7	“
“	“	“ 12	1294.2	“

It is evident from the above that the live-weight is a very uncertain criterion for judging of the effect of a ration, and that for scientific purposes, where an accurate knowledge of the gain or loss of flesh and fat is required, it is almost worthless.

These remarks are not to be understood as calling in question the practical value of the live-weight. The scales are (or should be) an important adjunct to the stable, but it is all the more necessary, on that account, to know how far their indications can be trusted, while every one who undertakes to make feeding experiments should be aware of the exceeding ambiguity which attaches to *small* changes of weight.

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* 1 German lb. equals about 1.1 English lb.

The foregoing explanations make evident how much labor and care are necessary in order to determine, with any certainty, the nutritive value of even a single article of fodder for a single class of animals, and it is no cause for surprise that the theory of feeding can only reach its complete development in all directions slowly. When the question is only of the gain or loss of flesh, the method of experiment, as we have seen, is much simpler and less laborious and demands less expensive apparatus, than when the effect of the ration as a fat-producer is to be determined; and it is therefore natural that the laws of "flesh-building" are already very thoroughly explored, while in regard to the circumstances under which the greatest and most advantageous production of fat or work is to be obtained we are much more in the dark.

CHAPTER VI.

FORMATION OF FLESH.

§ 1. INTRODUCTORY.

IN the foregoing chapters we have considered the composition of the animal body and of those substances which serve to nourish it—the nutrients, the manner in which these nutrients are digested and resorbed so as to become part of the body, and in outline the changes which they undergo in the body and the forms in which they are finally excreted from it.

We saw that we may regard the body as composed essentially of protein, fat and mineral matters. The object of feeding is a production of these several ingredients in greater or less quantity. If an animal is simply to be kept in the same bodily condition—to be wintered, *e. g.*—we aim only to produce enough to supply the unavoidable destruction of tissue that goes on in every living organism, while in feeding for milk, or in fattening, we endeavor to obtain the most rapid production possible, especially of protein and fat; but in any case *some* production must take place.

Plainly, then, it is of the highest importance to know the laws that regulate the formation of flesh (protein) and fat, from what ingredients of the food they are formed, and what quantities and proportions of the latter will produce the desired effect most rapidly and cheaply. In this chapter we shall consider the laws regulating the production of flesh, and in the following one those governing the production of fat.

The Laws of the Formation of Flesh have been most thoroughly studied in the carnivora, but they are essentially the same for all the higher animals.

The various races of animals differ, indeed, as regards the fodder which they chiefly consume, as well as in their greater or less digestive power for certain kinds of fodder; but the real nutrients which are resorbed from the digestive apparatus, even with the most varied rations, are always the same, viz.: protein, fat, and sugar, together with water and certain salts. Since, furthermore, in all mammals at least, the corresponding organs are entirely similar in their structure, chemical composition, and functions, the decomposition of their constituents must follow the same course, *i. e.*, the substances once resorbed and taken up into the circulation decompose or are laid up in the body according to the same laws.

Moreover, the laws derived from experiments on carnivora have been completely confirmed in their general scope and bearing in all the experiments recently made on herbivora, viz., on oxen, cows, sheep, and goats, though the total amount of material decomposed or stored up in the body varies according to the proportions of the various classes of nutrients contained in the normal fodder of the animal.

The food of the carnivora consists chiefly of protein and fat, while the herbivora consume relatively less of these but large quantities of carbhydrates.

The ability of the carnivora and herbivora to resorb the various nutrients is not, however, so different as is generally supposed; it has been shown, *e. g.*, that a dog is able to digest and resorb, daily, as much as 15 grms. of starch per kilogramme of live weight, while a well-fed milk-cow, or even a fattening ox, resorbs from its fodder, daily, not more than 12 to 18 grms. of carbhydrates per kilogramme live weight. Similar facts have been observed regarding the resorption of protein, but not regarding that of fat, which is digested by the carnivora in relatively far greater quantity than by herbivora.

A large part of our knowledge of the laws of the formation of flesh is due to the labors at Munich of Karl Voit, at first in conjunction with Bischoff and, later, alone and with v. Pettenkofer. These investigators have made a great number of experiments, chiefly on dogs, determining the gain or loss of flesh and the total amount of protein decomposed in the body by the method described in Chapter V., and to them belongs the honor, both of having established a reliable method of investigation (see Chapter IV., pp. 94–97) and of having applied it successfully to the solution of the important question of the effect of food on the gain or loss of flesh. The results stated in this chapter are largely those of the above-named investigators.

Protein Consumption.—In considering the laws of flesh-formation, there are two parallel processes to be distinguished.

In the first place, in every living organism a certain quantity of albuminoid matter is daily destroyed in the vital processes, and its nitrogen appears as urea, etc., in the urine.

The amount of protein or flesh thus destroyed may vary greatly in different animals, or in the same animal at different times, but it can only cease entirely with the cessation of life, and cannot sink below a certain minimum amount without serious derangement of the vital functions. This continual and necessary process we shall call *protein consumption.*[*] This, of course, must not be confounded with the amount consumed by the animal in its food. It denotes a very different thing.

In the second place, from a sufficient and suitable fodder more protein may be resorbed into the circulation than is needed to supply the consumption under the given circumstances, and this surplus produces a deposition of protein and becomes part of the body. Evidently, whatever decreases the protein consumption and increases the amount deposited in the tissues is so much gained in feeding.

The protein consumption is not to be considered as waste, for it is necessary to the vital processes and, as we shall see, is generally greater the richer the food, but an improperly constituted ration may unnecessarily increase it and result in an unproductive use of fodder. The smaller the protein consumption can be made, consistently with the proper performance of the vital functions, the more of the protein of the food is available for the production of flesh.

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[*] We have seen (Chap. V.) that from the urinary nitrogen we can calculate the amount of either dry protein or fresh flesh decomposed in the body, by multiplying respectively by 6.25 or 29.4. In most of the experiments which have been made on carnivora the results have been expressed as flesh, while in those executed on herbivora the results have been calculated as dry protein. In the one case we should speak of the "consumption of flesh," and, in the other, of the "protein consumption." The two are equivalent, but not equal, the consumption of flesh being 4.7 times the protein consumption.

In the following pages we shall have occasion to use both expressions.

§ 2. Organized and Circulatory Protein.

Protein Consumption during Hunger.—The following table * gives, in grammes, the quantities of urea daily excreted by a fasting dog weighing about 35 kilogrammes (77 lbs.), the excretion of urea being, as we have seen, an exact measure of the protein consumption in the body.

No. of Experiment.	11.	5.	14.	15.	16.
Previous food per day.	2,500 grms. meat.	1,800 grms. meat and 250 grms. fat.	1,500 grms. meat.	1,500 grms. meat.	
	Grms.	Grms.	Grms.	Grms.	Grms.
Last day of feeding	180.8	130.0	110.8	110.8	24.7
1st day of fasting	60.1	37.5	29.7	26.5	19.6
2d “ “	24.9	23.3	18.2	18.6	15.6
3d “ “	19.1	16.7	17.5	15.7	14.9
4th “ “	17.3	14.8	14.9	14.9	13.2
5th “ “	12.3	12.6	14.2	14.8	12.7
6th “ “	13.3	12.8	13.0	12.8	13.0
7th “ “	12.5	12.0	12.1	12.9	....
8th “ “	10.1	....	12.9	12.1	....
9th “ “	....	....	....	11.9	....
10th “ “	....	....	....	11.4	....

It will be observed that in these experiments the protein consumption (as measured by the excretion of urea) was very unequal on the last day of the feeding and the first days of hunger; furthermore, that when food was withheld the protein consumption at once sank, rapidly at first but at last very slowly, till at about the sixth day it became practically the same in all cases and so continued during the remaining days, its amount being represented by the excretion of about 12 grammes of urea. A large number of other experiments gave the same result.

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* Voit: Zeitschrift für Biologie, II., pp. 307–365.

The Two Factors determining Protein Consumption.—It is plain from the above figures that there are two factors which determine the amount of protein destroyed in the body; a constant one, which caused in these experiments an excretion of about 12 grammes of urea per day, and a variable one, which caused the excretion of very different quantities of urea at first, and which gradually disappeared as the experiments progressed.

No. of Experiment.	11.	5.	14.	15.	16.
Previous food per day.	2,500 grms. meat.	1,800 grms. meat and 250 grms. fat.	1,500 grms. meat.	1,500 grms. meat.	
	Grms.	Grms.	Grms.	Grms.	Grms.
Last day of feeding	168.8	118.0	98.8	98.8	12.7
1st day of fasting.	48.1	25.5	17.7	14.5	7.6
2d " "	12.9	11.3	6.2	6.6	3.6
3d " "	7.1	4.7	5.5	3.7	2.9
4th " "	5.3	2.8	2.9	2.9	1.2
5th " "	0.3	0.6	2.2	2.8	0.7
6th " "	1.3	0.8	1.0	0.8	1.0
7th " "	0.5	0.0	0.1	0.9	....
8th " "	−1.9	....	0.9	0.1	....
9th " "	....	....	....	−0.1	....
10th " "	....	....	....	−0.6	....
Total *..........	244.3	163.7	135.3	131.1	29.7

* Omitting the negative quantities.

If we assume 12 grammes of urea as the amount due to the constant factor, and subtract this from the total excretion on the several days in these experiments, the remainders will exhibit the action of the variable factor. In the table on the opposite page this has been done.

This table shows still more clearly the great influence of the variable factor at first and its speedy disappearance when the supply of food is cut off.

Organized and Circulatory Protein.—It is evident from these and a great number of similar results that the protein of the living body exists in two forms—a comparatively stable one, which decomposes slowly and yielded in these experiments about 12 grammes of urea per day, and an easily decomposable one, whose amount depends on the food and which is rapidly destroyed when food is withheld. The quantity of the latter is small as compared with that of the former. In experiment **11**, for example, where its amount was greatest, its total quantity was only about 3,364 grammes of flesh (244.3 grms. of urea × 13.77), while the animal weighed about 35,000 grammes.

Voit designates the stable protein of the body as *organized protein*, and considers that it makes up the mass of the organs; while the variable and easily decomposing quantity he calls *circulatory protein*. Under the latter he does not include the protein of the blood and lymph, but only the dissolved protein which penetrates from these into the tissues and bathes the cells in a nourishing fluid.

Some good authorities dispute the correctness of the names circulatory and organized protein, but there is no dispute as to the correctness and importance of the distinction which they imply between the two forms of protein in the body. For our present purpose this is the important thing, and we shall use Voit's nomenclature, understanding by *organized protein* the great mass of slowly decomposing nitrogenous compounds in the body, and by *circulatory protein* the relatively small quantity of easily decomposable albuminoids which it contains.

The quantity of circulatory protein in a poorly nourished body is only small, not amounting in hunger to one per cent. of the weight of the organized albuminoids, but its amount is increased by an abundance of protein in the food, and may, at least in the carnivora, rise to five per cent. or more. But, be the quantity of circulatory protein large or small, the greater part of it, generally seventy to eighty per cent., is consumed in the course of twenty-four hours, and an exactly corresponding quantity of nitrogen excreted in the urine as urea, etc.; while of the organized protein, at most not more than 0.8 per cent. is consumed—that is, the protein consumption in the body takes place almost wholly at the expense of the circulatory protein.

It can be by no means assumed, as was formerly done, that all organs of the body are subject to a rapid metamorphosis, and that in the course of a comparatively short time the whole organism to the last atom is renewed and rebuilt.

This is only the case as regards a few tissues. The blood corpuscles, *e. g.*, and the milk glands in the period of their greatest activity, are rapidly destroyed and as rapidly re-formed; but by far the greater part of the organs. have, when once formed, a much greater stability, although the contents of the cells vary much in quantity and quality with the varying food of the animal. The circulatory protein, on the contrary, suffers a continual and rapid destruction, and must be continually replaced by protein from the food.

Other Experiments.—That the organized protein of the animal body is destroyed far less easily than the circulatory protein, is also indicated by more direct experiments which have lately been made.

If by any means it were possible to introduce into the body of an animal which had been deprived of food long enough to destroy its circulatory protein, albuminoids in the form of a living organ from another animal, we should expect that, according to Voit's theory, these albuminoids would be but slowly destroyed in the body. Forster* attempted to accomplish this by the transfusion of blood, and found that the protein of living blood, which may be regarded as organized, was but slowly destroyed in the system, while simple solutions of albumin produced an immediate and considerable increase in the excretion of urea. It is noticeable, however, that his results show that albumen thus injected seems to be more slowly decomposed than that taken in the food.

Tschieriew† has compared the behavior of transfused blood with that introduced into the stomach, with the following results:

	Nitrogen given. Grms.	Nitrogen excreted. Grms.
Blood fed	13.19	14.55
" transfused	19.09	6.85
" fed	14.38	14.43
No food	0.00	4.65
Blood transfused	18.53	10.60

These figures show plainly that the albuminoids of the blood, after they had passed through the digestive apparatus, were much more readily oxidized in the body than before.

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* Zeitschrift für Biologie, XI., 496.

† Biedermann's 'Central-Blatt für Agr. Chem.,' X., 98.

§ 3. Feeding with Protein alone.

In order to obtain a clear idea of the various factors which determine the consumption of protein, on the one hand, and its deposition on the other, it will be best, in the first place, to consider the phenomena produced when the several nutrients are fed alone, and afterward the effect of two, or of all of them together.

Consumption dependent on Supply.—The numerous researches made by Voit * have shown most fully that *the consumption of protein in the body is largely determined by the supply of protein in the food.* That the excretion of urea, and consequently the protein consumption, was influenced by the food to a very considerable extent, had already been noticed, but this observer has the merit of having fully investigated the subject and given it the prominence it deserved. His experiments were made chiefly on dogs; the following are some of the results obtained in different experiments on the same dog with a diet of various quantities of pure, fat-free meat:

	Grms.	Grms.	Grms.	Grms.	Grms.	Grms.	Grms.	Grms.	Grms.
Meat eaten per day......	0	300	500	900	1,200	1,500	2,000	2,500	2,660
Urea excreted..........	12	32	40	68	88	106	144	173	181
Corresponding to flesh...	165	442	552	938	1,214	1,463	1,987	2,387	2,498

The consumption of flesh varied from 165 grms. per day during hunger to nearly 2,500 grms. with the largest amount of albuminoids in the food, and almost exactly in proportion to the amount of the latter. In all these experiments by far the larger part of the protein of the food was converted into *circulatory protein*, which was rapidly consumed in the vital processes. That this is always the case on a purely albuminoid diet is shown by the scores of similar experiments which might be cited.

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* Zeitschrift f. Biologie, III., 1.

Similar experiments on our herbivorous domestic animals have given in the main the same result, except that the protein consumption has generally been found to be less in proportion to the weight of the animal than in the carnivora, a fact which, however, as we shall see, is in great part due to the large amount of non-nitrogenous matter in the food of these animals. Could they be fed on pure protein, as was the dog in the above experiments, it is probable that the protein consumption would be correspondingly increased.

The Consumption does not depend on the Supply alone.—With the same amount of protein in the food the protein consumption in the body may be very unequal in the same animal at different times, as the following results strikingly show.

Meat eaten. Grms.	Previous food.	Consumption of flesh per day. Grms.	Gain or loss of flesh. Grms.
2,000.	2,500 grms. meat.	2,229	— 271
"	2,000 " " +250 grms. fat.	2,069	— 69
"	1,500 " "	1,920	+ 80
"	200 " " + 300 gelatin.	1,753	+ 247
"	0	1,677	+ 323
"	450 grms. starch.	1,383	+ 617
"	175 " meat + 300 fat.	1,365	+ 635

The same amount of food caused in one case a loss of 271 grms. of flesh, and in another a gain of 635 grms., and a corresponding variation in the protein consumption is observed. This can only be explained by the difference in the previous food. Where, by an abundant supply of albuminoids, a large amount of *circulatory protein* had been formed in the body, a decrease of the albuminoids of the food caused a decrease in the protein consumption, but not to an amount corresponding to the decrease in the supply; the animal lost flesh. On the other hand, an increased supply of albuminoids caused an increase in the protein consumption; but the increase, like the decrease in the other case, was not proportional to the increased supply, and a gain of flesh resulted. The figures of the above table refer to the first day of the new feeding, and we gather from them that the protein consumption is dependent not only on the amount of protein in the food but on the bodily condition resulting from the preceding feeding.

Equilibrium soon established with Food Supply.—The gain or loss of flesh observed on the first day after a change in the supply of protein does not usually continue long. Within a short time—usually two to four days—the consumption of protein in the body becomes equal to the amount supplied in the food, and no further gain or loss of flesh takes place. The two following examples may serve to illustrate this.

Food.	Previous food.	CONSUMPTION OF FLESH.			
		Day before.	1st day.	2d day.	3d day.
		Grms.	Grms.	Grms.	Grms.
2,500 grms. meat.	1,800 grms. meat.	1,800	2,153	2,480	2,532
2,000 " "	2,500 " "	2,500	2,229	1,970	....

In each, the protein consumption was in equilibrium with the food supply at the beginning of the experiment. In the first case an increase of 700 grms. in the amount of meat eaten caused a rapid increase in the protein consumption, till in three days the two were again nearly in equilibrium. In the second experiment the same thing is observed as to the decrease of the protein consumption. The gain or loss of flesh in either case is very trifling, amounting respectively to 335 grms. and 199 grms. in a dog weighing about 35 kilogrammes. Nearly all of the additional 700 grms. per day in the first experiment was converted into circulatory protein and rapidly destroyed, while in the second the subtraction of 500 grms. per day decreased proportionately the reserve of circulatory protein and the amount consumed.

The experiments given above are simply examples taken from a large number of similar ones, made both on carnivora and herbivora, all of which have given the same result, viz.: *the animal body puts itself, after a longer or shorter time, into equilibrium with whatever quantity of albuminoids it receives in its fodder above that necessary to maintain it in average condition.* That is, a certain minimum quantity of albuminoids is necessary to prevent the starvation of the animal. An increase of the supply above this quantity causes a slight gain of flesh for a short time, but a *rapid* increase in the amount of circulatory protein and consequently in the protein consumption, and, finally, exactly as much nitrogen is excreted in the urine (and milk) as is taken in the food. We might compare the stock of circulatory protein in the body to a mass of water contained in a vessel with a small aperture in the bottom. If there is no supply, it quickly runs out. If a small stream of water be let in at the top, a small supply of water may be maintained in the vessel. If a larger stream be admitted, the depth of water in the vessel will at once begin to increase, but, at the same time, the pressure on the bottom, and consequently the rapidity of the outward flow through the aperture, increases, and outflow and inflow soon come into equilibrium. If the supply be diminished, the level of the water sinks till the hydrostatic pressure causes the outflow to again equal the inflow.

The Protein Consumption during Fasting is not a Measure of the Amount necessary to sustain Life, as was formerly assumed to be the case. If to a fasting animal we give an amount of protein exactly equal to that daily consumed, this protein is converted into circulatory protein, and the consumption is correspondingly increased. In order to maintain an animal in average condition, we must give it, approximately, from two to two and a half times as much protein in its food as is consumed in the body during hunger, and when the food has been rich in albuminoids a much greater quantity is necessary to maintain the equilibrium once established.

When equilibrium is once reached, either by a gain or loss of flesh, as the case may be, exactly the same kind and quantity of food is necessary to keep the animal unaltered in the bodily condition in which it then is. Every state of the body, then, demands for its maintenance a certain definite fodder, and we cannot well speak of a superfluous consumption of food by animals as by plants, *i. e.*, of a wholly useless and unnecessary excess of some one nutrient. A *waste of fodder*, however, often occurs in practice, in so far as more fodder is given than is necessary for the object in view, *e. g.*, in the production of milk or wool and the feeding of draught animals and young cattle. Even in fattening, as we shall see later, the same or a better result may not infrequently be obtained with a fodder somewhat poor in albuminoids than with one containing a very large quantity of them.

The Rapidity with which Equilibrium is established varies.—It is greater the richer the food is in albuminoids and the less fat is contained in the body; in general, therefore, in the carnivora than in the herbivora.

The influence of the fat of the body in decreasing the protein consumption is of great importance. It has been proved beyond a doubt that in a fat body, the mass of flesh, the food, etc., being the same, the protein consumption is less than in a lean body. It is not, however, simply the absolute quantity of fat, but rather its amount relatively to that of the flesh which is the important point.

But not only is the protein consumption less in a fat body, *ceteris paribus*, but the rapidity with which equilibrium is reached after a change in the food is less.

The following are the results of two experiments, A on a lean animal (dog), B on a fat one:

	Increase of meat in food. Grms.	Equilibrium on	Gain of flesh. Grms.	Gain in per cent. of increased food.
A	1,800	3d day.	309	17
B	1,620	6th "	1,365	84

A smaller increase of protein in the food of the fat animal caused both a relatively and absolutely greater gain of flesh, which also continued twice as long. Numerous other examples of the same effect might be adduced, were it necessary.

As a consequence of this fact, a gain of flesh can be made more readily by herbivora than by carnivora, since the former are, as is well known, much inclined to the laying on of fat, and even when in medium condition generally contain relatively a much larger quantity of that substance than the carnivora. For the same reason we may often increase disproportionately the amount of albuminoids in the food of the herbivora without having to fear that it will all be converted into circulatory protein and rapidly consumed. Good results may often be attained in this way, but we should never, with these animals, leave out of account the bodily condition caused by the previous foddering. In the beginning of fattening, especially, the most appropriate fodder must be essentially different according to whether we have to do with lean and "run down" animals or with those which are already in good condition.

Effect of Salt on Protein Consumption.—A moderate addition of salt to the fodder increases the circulation of the juices of the body, and consequently the protein consumption; but the salt secures advantages, especially in the herbivora, which have already been spoken of. The feeding of salt is therefore especially in place when a greater energy of all the vital functions is desired, as in horses and well-fed working oxen, in young animals, and in male breeding animals, etc., while in fattening only so much should be given as is necessary to render the fodder savory, and is demanded for the normal nourishment of the animal.

Another action of salt is to increase the excretion of urine, often very considerably.

This is observed especially when the animal is prevented from much drinking, either purposely or in any other way. For the excretion of larger quantities of salt, more water is necessary, and this is withdrawn, in the first place, from that excreted by evaporation through the lungs and skin, and, if this is not sufficient, from the body itself. The live weight can therefore sink rapidly when large doses of salt and little water are given, while afterward, on the other hand, if more water is drunk, much of it may be laid up in the tissues, and the live-weight of the animal be again increased.

Influence of Water on the Protein Consumption.—Giving too large quantities of salt to animals is to be avoided for still another reason, viz.: that the animals are led to drink large quantities of water, if they have access to it. This causes an increased protein consumption, that is, an increased destruction of valuable fodder materials, especially when the larger quantity of water is not retained in the tissues but is rapidly removed by an increased excretion of urine.

Experiments by Voit on fasting animals showed an increase of the protein consumption in this way by as much as 25 per cent., and, according to observations by Henneberg,* in Weende, on oxen, the increase of the protein consumption, when the amount of water was increased 22.4 per cent., averaged 5.8 per cent. Even the last named increase is by no means insignificant; it amounts to a third, or perhaps even a half of the protein which otherwise might have been deposited in the body. In any case, in order to get the most advantageous results possible, especially in the feeding of young animals and in fattening, we must avoid everything which involves or leads to an excessive use of water; *e. g.*, too watery fodder, too high a temperature of the stall, too much salt, too much movement, etc. This is more especially to be observed in regard to sheep, since these animals drink voluntarily much less water in proportion to the dry matter of their fodder than cattle. In round numbers, the normal amount of water (in food and drink together) may be stated as 4 lbs. per pound of dry matter of the fodder for cattle, and half that quantity for sheep.

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* "Neue Beiträge," etc., 1871, p. 397.

In milk-giving animals an increased consumption of water is less disadvantageous, and may indeed cause an increased milk-production; but in this case, also, it is undoubtedly advisable not to exceed a certain limit as to the proportion of water in the fodder.

The Effect of Stimulants on the protein consumption seems to be inappreciable. The action on the nervous system seems to be caused by so minute a metamorphosis of albuminoid substance that it has no significance compared with the total protein consumption in the body. It is, however, another and as yet undecided question whether the increased nervous activity may not cause an increased consumption of fat in the body, as does muscular exertion, *e. g.*

§ 4. Feeding with Fat or Carbhydrates Alone.

Fat alone does not decrease the Protein Consumption.—This is shown plainly by the following results obtained by Voit[*] on a dog:

	Grms.	Grms.	Grms	Grms.	Grms.	Grms.	Grms.
Fat per day........	0	100	200	300	300	340	350
Flesh consumption.	170	185	155	187	165	205	291

We see at once that even the largest rations of fat are not able to stop or decrease the loss of flesh from the body, but seems rather to *increase* it slightly. This latter effect has been observed in other experiments, and appears to be due to the influence of the fat in drawing into circulation the organized protein of the body. It shows itself still more markedly when, along with the fat, an amount of albuminoids not sufficient to balance the consumption is given.

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[*] Zeitschrift f. Biologie, V., 329.

The effect is in every case small, and this action of fat is far more than counterbalanced by another which shows itself when it is fed along with a sufficient quantity of protein.

Carbhydrates alone do not decrease the Protein Consumption any more than does fat. The same amount of protein is oxidized and destroyed in the body as in the complete absence of food. They differ from fat, however, in the fact that they do not, like the former, slightly increase the protein consumption. They are simply without effect on it *when fed exclusively.*

§ 5. Feeding with Protein and Fat.

The Protein Consumption is determined chiefly by the Supply of it in the Food, just as it is in feeding exclusively with albuminoids, and any increase in the amount of the latter causes a corresponding increase in the former. Thus, Voit (*loc. cit.*) obtained the following results:

		Grms.	Grms.	Grms.	Grms.	Grms.	Grms.
Food	Fat	250	300	250	200	200	250
	Meat	150	176	250	500	800	1,500
Consumption of flesh per day		233	259	270	502	778	1,381

It is evident that the protein consumption in the body is greater, the larger the amount of protein in the food. The increase, however, is not quite as great as it would have been without the fat; for, other things being equal,

Fat decreases the Protein Consumption, and therefore increases the deposition of flesh in the body. This is most plainly shown if, after the body is in equilibrium with a certain quantity of albuminoids, fat be added to the food. The following example from Voit's researches illustrates this fact:

Date.	Food.		Urea per day. Grms.	Flesh consumption in body. Grms.
	Meat. Grms.	Fat. Grms.		
July 31.......	1,000	0	81.7	1,140
Aug. 1........	1,000	100	74.5	1,042
" 2........	1,000	300	69.3	970
" 3...	1,000	0	81.2	1,134

While the animal, when fed with 1,000 grammes of meat, was losing daily about 140 grammes of flesh, the addition of 300 grammes of fat served not only to prevent this loss, but to cause a slight gain.

This decrease of the protein consumption is not very considerable in a single day, amounting, in the dog used by Voit, to at most 168 grammes of flesh, or 45 grammes of dry protein, and varying from 1 to 15 per cent. of the total consumption. Its amount depends not only on the protein and fat of the food but also on the condition of the animal. The greater the amount of circulatory protein in the body, and the less fat it contains, the more of the protein of the food is converted into circulatory protein and consumed.

The Decrease of the Protein Consumption is no greater with a large than with a small Ration of Albuminoids, if the quantity of fat remains the same. This, indeed, follows from the statements of the first paragraph. An increase of the albuminoids of the food causes more circulatory protein to be formed, and, as a consequence, increases the consumption; and while the latter is less than it would be without the fat, the difference is not notably, if at all, greater than with the smaller amount of albuminoids.

The addition of the fat simply makes the consumption of protein *less than it would be without it under the same circumstances;* but this comparatively small decrease may sometimes make all the difference between a continual loss of flesh from the body and a state of equilibrium, or even a gain of flesh, and thus may be a most important factor in feeding, as illustrated in the experiments in the previous paragraph.

A dog weighing 35 kilogrammes (77 lbs.), when fed exclusively on pure meat, needs about 1,500 grammes daily in order to remain in good condition and in equilibrium as regards nitrogen. If, instead of this, he receives only 500 grammes, he loses, for a number of days, about 150 grammes daily of his own flesh; and if, after a considerable time, he comes into equilibrium with the smaller ration, he is wasted away and in wretched condition. But if, along with the 500 grammes of meat, about 200 grammes of fat be given, this loss of flesh is speedily checked, and when the protein consumption has come into equilibrium with the supply the animal remains in a sound and well-nourished condition. The addition of 200 grammes of fat so decreases the protein consumption, which was before greater than the supply, causing the animal to lose flesh constantly, that it is now equal to the latter, or perhaps, in some cases, less, so that a gain of flesh results. That is, we can keep the same amount of flesh on such an animal by feeding 500 grammes of meat and 200 grammes of fat, as by feeding 1,500 grammes of pure meat. In the former case, although the supply of protein is much less, the consumption of it in the body is correspondingly less; and though the animal may be less lively and energetic in its motions on this account, it may still be maintained in good condition for any length of time on such a ration without the least injury to its health.

That the protein consumption, as above stated, is less than when 1,500 grammes of meat are fed is due, in great part, to the decreased supply of albuminoids, the effect of this being the same as when only albuminoids are fed, as was explained and illustrated in the first paragraph of this section.

The effect of the addition of the fat is simply to decrease the consumption a little more; but this little carries it past the point of equilibrium, and so prevents the continual loss of flesh which takes place without it. The animal may even gain flesh on such a ration. In this case, therefore, the addition of 200 grammes of fat has saved 1,000 grammes of meat, as compared with a purely flesh diet. We are not, however, to understand that if to the large ration of 1,500 grammes of meat we add 200 grammes of fat, the daily flesh consumption will sink at once to 500 grammes or less, and that 1,000 grammes of flesh will be formed in the body. The protein consumption, as already insisted on, is dependent in the first place on the supply of albuminoids in the food, and an increase of the latter correspondingly increases the former;

so that, while a large quantity of protein would be daily consumed in the body with the large ration of albuminoids, the gain of flesh would be no greater, and might be even less, than with the smaller ration.

Fat may cause a long-continued Gain of Flesh.—We have seen that any gain of flesh caused by an increase of the albuminoids of the food continues but a short time. The additional albuminoids increase chiefly the amount of circulatory protein in the body and consequently the protein consumption, and equilibrium between the food and the body is speedily established.

If, however, the gain of flesh is caused by the addition of fat to the food, the case is different.

The fat seems to favor the formation of tissue, *i. e.*, of the more stable organized protein, which is less easily oxidized, and consequently, as is found by experiment, the gain of flesh caused in this way may continue for a comparatively long time, so that although the saving of protein effected by the fat may not be great in a single day, the total result is very considerable. It has been already shown (p. 133) that the fat deposited in the body has the same effect in this respect as that of the food.

The Gain of Flesh continues much longer on a medium than on a large Ration of Albuminoids.—The following experiments (see page 142) illustrate this.

The total gain up to the beginning of nitrogen equilibrium is seen to be in general no greater, and often less, with a large than with a medium ration of albuminoids. In details exceptions are to be expected, since the experiments were not all made consecutively, and since not only the supply of food but the bodily condition has much to do with the gain of flesh.

In order, then, to obtain as great and long-continued a

Length of Experiment. Days.	Food.		Total gain of flesh. Grms.	Gain per day. Grms.	Whether nitrogen equilibrium.
	Fat. Grms.	Meat. Grms.			
32.	250	500	1,794	56	Not yet.
4.	200	800	320	80	"
3.	250	1,000	375	125	Nearly.
3.	250	1,250	294	98	"
4.	250	1,500	476	119	"
10.	150	1,500	104	10	Quite.
23.	30–150	1,500	889	38	Nearly.
7.	250	1,800	854	122	Quite.
3.	250	2,000	352	117	Nearly.

deposition of flesh in the body of a dog, *e.g.*, as possible, we should not feed large quantities of meat with fat. The absolute quantity of albuminoids in the food does not determine the gain, but only the protein consumption. Neither is it the absolute quantity of fat that determines the gain, but the relation between the two, together with the bodily condition.

This being the case, we should first endeavor to ascertain what ratio of albuminoids to fat gave the best results, and then, having compounded a ration in accordance with this, should endeavor to induce the animal to eat as much as possible of it. Two extremes ought to be equally avoided; too much albuminoids would cause an unnecessary protein consumption in the body, while if the ration contained an excess of fat, it might be impossible for the animal to eat enough of it to supply himself with the necessary amount of protein.

In the fodder of the herbivora the action of fat in decreasing the protein consumption does not show itself so plainly, its action being masked by the presence of large quantities of carbhydrates, which, as we shall see, have an effect similar to that of fat.

Moreover, the amount of fat in the fodder of the ruminants cannot safely exceed a certain easily-reached limit. Small quantities of fat exert in general a favorable influence; larger quantities, however, are often very injurious, causing disturbance of the digestion and an increasing lack of appetite. The different modifications of fat, however, behave very differently in this respect, and the fat of the food certainly deserves attention, especially in the feeding of young animals and in fattening, and likewise in case of horses, and in general whenever the fodder is rich in albuminoids.

§ 6. FEEDING WITH PROTEIN AND CARBHYDRATES.

The Carbhydrates act analogously to Fat on the consumption of protein and its deposition in the body. Like it, they do not suspend the protein consumption, which increases or decreases with the amount of protein in the food; like it, they decrease the protein consumption somewhat, but not greatly; like it, too, they enable an animal to subsist or even gain flesh on a much smaller quantity of albuminoids in its food than would suffice were the ration composed of pure protein.

The action of the carbhydrates on the formation of flesh has been investigated both in carnivorous and herbivorous animals.

In the previous sections we have been occupied exclusively with experiments on carnivora, for the reason that it is practically impossible to feed herbivorous animals on pure protein or protein and fat; but the general principles deduced from the experiments on carnivora are applicable also to herbivorous animals. In the present section we shall give special prominence to experiments on domestic herbivorous animals, and shall take occasion to point out, in passing, some confirmations of the results obtained on carnivora by Voit and others.

The ordinary fodder of herbivorous animals, leaving out of consideration, for the present, water and mineral matters, consists essentially of protein and carbhydrates with small quantities of fat.

A large number of experiments on these animals have been made. As of especial importance for our present purpose may be mentioned those of Grouven,* at Salzmünde, and of Henneberg & Stohmann,† at Weende, on oxen; those of G. Kühn & M. Fleischer,‡ at Möckern, on milk cows; and those of E. Schulze & M. Märcker, § in Weende, on sheep.

Of these, the Weende experiments on oxen in particular are of the highest value, both for our present purpose and many others, having been executed in the most careful and thoroughly scientific manner.

The Protein Consumption is Determined by the Supply in the Food.—The following experiments on oxen by Henneberg & Stohmann (*loc. cit.*), in which the amount of protein in the food varies while that of the non-nitrogenous nutrients remains essentially the same, illustrate this fact, which is shown also in all the other experiments cited.

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* Zweiter Salzmünde Bericht, 1864.

† "Beiträge zur Begründung einer Rationellen Fütterung der Wiederkäuer," 1864, and "Neue Beiträge," etc., 1871.

‡ Landw. Versuchs-Stationen, XII., 197 and 450.

§ Journal für Landwirthschaft, 1870 and 1871.

The non-nitrogenous matter of the food here includes the fat reduced to its equivalent of starch (p. 157); the numbers in the last three columns express dry protein (nitrogen × 6.25) and not fresh flesh.

No. of Experiment.	Non-nitrogenous matter digested. Lbs.*	Protein digested. Lbs.	Protein consumption. Lbs.	Gain of Protein. Lbs.
1860–1861.				
17	10.23	1.50	1.00	0.50
18	10.10	2.06	1.43	0.63
25	14.60	2.50	2.12	0.38
26	14.49	3.37	2.75	0.62
21	14.08	2.19	1.13	1.06
20	13.73	3.00	1.81	1.19
1865.				
Av. of 5 & 6.	11.60	0.84	0.86	−0.02
Av. of 4, 7 & 8.	11.95	2.52	1.99	0.53

These results show plainly that the addition of more protein to a fodder causes chiefly an increase in the circulatory protein of the body, and to a far less degree a gain of flesh, and fully confirm the conclusions drawn from similar experiments on dogs. At the same time it is obvious that in these experiments there was a greater tendency toward the laying on of flesh than was the case in those on carnivora; a larger proportion of the total protein of the ration and of the added protein went to form organized protein.

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* German pounds. 1 lb. German = 1.1 lb. av.

Some experiments on goats by Stohmann,* which strikingly illustrate the influence of the supply on the protein consumption, may also be mentioned. The following table contains all the essential data:

	Date of Experiment.	FODDER PER DAY.		Protein digested per day. Grms.	Protein consumption † per day. Grms.	Gain of protein per day. Grms.
		Hay. Grms.	Linseed meal. Grms.			
1.	May 23–29..	1,500	100	111.6	66.6	1.9
2.	June 6–12 ..	1,450	150	125.0	79.4	9.0
3.	" 20–26..	1,400	200	132.2	90.6	11.1
4.	July 4–10...	1,350	250	150.9	90.1	23.4
5.	" 25–31..	1,250	350	170.5	101.6	18.3
6.	Aug. 8–14 ..	1,100	500	193.8	117.9	27.4
7.	" 22–28..	950	650	221.4	143.1	30.6
8.	Sept. 5–11..	800	800	257.2	173.7	27.4
9.	" 19–25..	1,600*a*.	0	92.9	56.3	−4.4
10.	Oct. 3–9....	1,600*b*.	0	74.1	41.9	6.4

Nothing could be more evident than the dependence of the protein consumption on the supply in these experiments.

We have seen that in a fasting dog the protein consumption is at once increased by even the smallest ration of meat. Some experiments by Grouven (*loc. cit.*) seem

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[*] "Biologische Studien," Heft 1, p. 121.

[†] Exclusive of the protein contained in the milk, which varied but slightly.

to indicate that the effect on the herbivora may be different.

He observed that in full-grown oxen the protein consumption was decidedly less on a ration of rye-straw than during hunger, and that the addition of pure non-nitrogenous nutrients to the straw decreased it still more.

Ox No. I.

Fodder per day.	Live weight. Lbs.	Nitrogen digested. Grms.	Consumption of flesh. Grms.	Loss of flesh. Grms.
0	1,019	....	950	625
8.7 lbs. straw..............	959	5.2	475	326
6.6 " +2.2 lbs. sugar.	990	3.2	250	176
6.5 " +3.3 "	968	4.6	230	110

Ox No. II.

0	791	....	1,109	640
6.6 lbs. straw..............	777	5.5	360	218
5.3 " +2.2 lbs. sugar.	799	2.7	250	191
5.3 " +3.3 "	781	3.0	395	320

Ox No. III.

0	1,150	....	1,427	1,525
9.2 lbs. straw..............	1,155	0.5	771	757

The accuracy of these results is impaired by the facts that between the experimental periods the animals received an abundant but not uniform fodder, and that the preliminary feeding was in each case so short (3 to 6 days) as to render it doubtful whether the effect of the new fodder was fully established.

Furthermore, the dung often contained almost as much, and sometimes even more nitrogen than the fodder, showing that the former contained considerable quantities of nitrogenous matters coming from the body. The result of this, of course, is that the numbers for digested protein and for the consumption of flesh are too low; those for the loss of flesh (nitrogen of fodder less that of dung and urine), however, are unaffected by this source of error.

If we are to accept this result of Grouven's as correct, we must ascribe it to the large quantities of non-nitrogenous matter which were digested along with the small amount of protein, and which would tend to diminish the protein consumption. This action of the carbhydrates is seen also in most of the experiments in which these substances were added to the straw.

Of somewhat the same nature as Grouven's results are those which show that addition of protein to a fodder poor in this substance may cause a considerable gain of flesh.

The experiments by G. Kühn & M. Fleischer (*loc. cit.*), on cows, serve to illustrate this. Two cows were fed during a first period with hay, either alone or with the addition of starch, and in a second period a nitrogenous bye-fodder was added. The hay used contained an unusually small quantity of protein (Nutr. ratio, 1:12), and a comparatively small amount of it was consumed, so that the food in the first period was far from rich. Even the addition of the nitrogenous bye-fodder in the second period did not make it particularly so, but it nevertheless caused a considerable gain of flesh, which continued for some time.

The experiments covered, including the preliminary feeding, from twenty-two to twenty-four days, and the gain in the last six days was fully equal to that at the beginning. The table shows the results obtained during the experiment proper (exclusive of the preliminary feeding), and also the protein consumption and the gain of protein for the last five days of the feeding with nitrogenous bye-fodder.

Cow No. I.

Date.	Fodder.	DIGESTED PER DAY.		Nutr. ratio 1 :	Protein consumption per day. Grms.	Gain of protein per day. Grms.
		Protein. Grms.	Carbhydrates. Grms.			
Dec. 26–Jan. 6....	Hay..............	393	4,800	12.2	187	−5.9
Jan. 17–Feb. 1 " 27– " 1 ..	Hay and rape-cake	680	4,985	7.3	343 345	+124.7 +117.8

Cow No. II.

Date.	Fodder.	Protein. Grms.	Carbhydrates. Grms.	Nutr. ratio 1 :	Protein consumption per day. Grms.	Gain of protein per day. Grms.
Feb. 16–Mar. 3....	Hay and starch...	394	5,550	14.1	156	+ 40.0
Mar. 12–27 " 22–27	Hay and beans....	728	5,570	7.6	333 332	+182.2 +181.9

The addition of protein to a ration poor in this substance caused a considerable gain of flesh by the animals. At the same time, it did not fail to affect the protein consumption, approximately doubling it in each case. We conclude, then, that in the case of the herbivora protein added to a ration does not pass so promptly and completely into circulatory protein as it does in the carnivora, but may cause a considerable gain of flesh. This inclination toward the formation of organized rather than circulatory protein seems to be a characteristic of the herbivora, perhaps due in part to the large amounts of non-nitrogenous food which they consume and in part to the considerable quantities of fat usually laid up in their bodies, and is a circumstance favorable to economy in feeding.

But though increasing the proportion of protein in a ration may cause a gain of flesh, the experiments by Stohmann, already cited, show that when the food is already rich in this substance the gain is much smaller and is accompanied by a greatly increased protein consumption.

Carbhydrates decrease the Protein Consumption.—The following experiments by Voit* on a dog show that

Date of Experiment.	Food.		Flesh consumption. Grms.
	Meat. Grms.	Carbhydrates. Grms.	
June 23–July 2, 1859........	500	300–100	502
July 2–5, 1859..............	500	0	564
July 4–10, 1864............	800	0	826
" 10–19, "	800	100–400	763
" 19–20, "	800	0	895
July 23–26, 1864............	1,000	0	1,028
" 26–28, "	1,000	100–400	902
" 28–Aug. 1, 1864........	1,000	0	1,112
June 29–July 8, 1863.......	1,500	0	1,599
July 8– " 13, "	1,500	200	1,454
Jan. 6, 1859................	2,000	0	1,991
" 7–11, 1859.............	2,000	200–300	1,792

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* Zeitschrift f. Biologie, V., 484.

the carbhydrates exert the same influence on the protein consumption as does fat, viz.: render it less than it otherwise would be.

In almost every case the effect of the addition of carbhydrates was not only to decrease the protein consumption but to render it less than the supply, and thus to cause a gain of flesh instead of the loss which had been taking place.

The action of the carbhydrates in decreasing the protein consumption is also to be seen in experiments on herbivora, though in these it is seldom so sharply expressed as in the results just given, because these animals, in any case, receive large amounts of carbhydrates and the effect of a further addition is therefore comparatively small.

Grouven's experiments show plainly the decrease of the protein consumption caused by the addition of sugar, even to straw fodder, which of itself contains much carbhydrates and little protein.

Some of Henneberg & Stohmann's experiments in 1865 also show this action of the carbhydrates. The quantities are per day and head.

a. FODDER RICH IN PROTEIN.

	Protein digested. Pounds.	Carbhydrates and fat digested. Pounds.	Nutritive ratio.	Protein consumption. Pounds.	Gain of protein. Pounds.
Ox II. Experiment 7...	2.60	10.95	1 : 4.2	2.14	0.46
" " 8...	2.51	12.51	1 : 5.0	1.83	0.68

b. FODDER POOR IN PROTEIN.

	Protein digested. Pounds.	Carbhydrates and fat digested. Pounds.	Nutritive ratio.	Protein consumption. Pounds.	Gain of protein. Pounds.
Ox I. Experiment 2...	0.82	7.22	1 : 8.8	0.83	−0.01
" " 1...	0.78	9.99	1 : 12.8	0.78	0.00
Ox II. " 5...	0.89	11.08	1 : 12.4	0.97	−0.08
" " 6...	0.78	12.12	1 : 15.6	0.74	+0.04

Here, again, an increase of the carbhydrates, though accompanied by a slight decrease of the protein, changed a loss of flesh into a gain, as well as diminished the protein consumption.

Further confirmation of this effect of the carbhydrates is found in the frequently observed fact that in the great majority of cases where the supply of albuminoids is sufficient to cause any production of flesh, the greatest *relative* gain is produced by rations having a wide nutritive ratio, that is, a large proportion of carbhydrates to albuminoids.

This fact is well shown by the following selection from the experiments of Schulze and Märcker (*loc. cit.*) on sheep, which are arranged according to the nutritive ratio. They were not all made on the same animal, nor at the same time, and are only comparable in a general way ; but, being tolerably numerous, they are sufficient to illustrate our present point. The results are per day and head. The protein in the daily growth of wool, amounting to about five grammes is not included in the gain of protein.

No. of Experiment.	Protein digested. Grammes.	Nutritive ratio.	Protein consumpt'n. Grammes.	Gain of protein. Grammes.	Gain in per ct. of amt. digested.
Experiment 6	30.6	1 : 17.4	24.3	1.4	4.6
Experiment 12	67.9	1 : 9.4	54.8	8.0	11.8
" 3	59.5	1 : 8.9	45.9	9.0	15.1
" 11	68.1	1 : 8.6	56.2	6.8	10.0
" 2	59.7	1 : 8.6	49.1	5.5	9.2
" 10	72.5	1 : 8.1	54.7	12.7	17.5
" 8	85.8	1 : 7.7	63.6	17.3	20.1
Average					14.0
Experiment 7	116.8	1 : 4.9	96.0	15.9	13.7
" 9	156.6	1 : 3 7	142.5	9.0	5.8
" 17	248.3	1 : 2.2	237.6	6.1	2.5
Average					7.3

The very wide nutritive ratio of Experiment 6 caused only a very small gain, because the absolute amount of protein was very small, but that any gain at all was made is doubtless due to the decrease of the protein consumption by the large amount of carbhydrates.

The other experiments show in general that a larger proportion of the protein of the food is applied to the production of flesh when the food has a medium nutritive ratio than when it has a very narrow one. In detail, exceptions are to be expected, since, as above stated, the experiments were not all made at the same time and the bodily condition has much to do with the effect of a ration.

Stohmann's experiments on goats, already described (p. 146), also illustrate the advantage of a medium nutritive ratio, as the following table shows:

	Protein digested per day. Grms.	Nutritive ratio.	Gain of protein per day. Grms.	Gain in per cent. of digested protein.
1.	111.6	1 : 5.87	1.9	1.8
2.	125.0	1 : 5.42	9.0	7.3
3.	132.2	1 : 5.08	11.1	8.3
4.	150.9	1 : 4.78	23.4	15.9
5.	170.5	1 : 4.22	18.3	10.5
6.	193.8	1 : 3.27	27.4	14.3
7.	221.4	1 : 2.84	30.6	14.0
8.	257.2	1 : 2.55	27.4	10.9

The *relative* gain of protein increased up to a nutritive ratio of 1 : 4.78, and then decreased.

These and many other experiments which might be adduced show that a larger proportion of the digestible protein of a ration is applied to productive purposes when that ration also contains abundance of non-nitrogenous nutrients.

We must beware, however, of hastily concluding that a wide nutritive ratio is the most profitable for the production of flesh. The amount of fodder which an animal can consume is limited, and, if the nutritive ratio be made very wide, the absolute amount of protein in the quantity of food daily eaten will be insufficient to supply material for production.

Moreover, the actual number of pounds of flesh gained per day is often greater on a ration pretty rich in albuminoids, as, for example, in the experiments on sheep and goats just cited, though, of course, accompanied by a large protein consumption in the body. The best pecuniary results may, under some circumstances, be reached by a ration having a rather narrow nutritive ratio and producing a *rapid* gain of flesh, even at the expense of an increased protein consumption; while, under other circumstances, a wider nutritive ratio and a slower and more economical production might be more remunerative. Extremes in either direction, however, are likely to be unprofitable.

Carbhydrates may cause a long-continued Gain of Flesh.—We saw in the previous section that a fodder of protein and fat could, under proper conditions, cause a long-continued gain of flesh, while the gain caused by an increase of the protein of the food was usually only temporary. The same fact is true of feeding with protein and carbhydrates.

It is to be remembered, however, that the fodder of our domestic animals always contains considerable quantities of carbhydrates, and that, consequently, the effects of a change from one method of feeding to another are not so sharply manifested as in the carnivora. To this is to be added that the digestive process lasts a considerable time in the herbivora, so that remnants of the old fodder may be resorbed along with the first portions of the new, and thus the change of fodder be made in reality a gradual one.

In general the gain of flesh produced by a ration containing much carbhydrates continues for a considerable length of time, while that caused by a ration poor in these substances but rich in protein, although it may be greater at first, does not continue as long.

For example, in the experiments of Kühn & Fleischer on cows (p. 149) the addition of protein to a ration containing much carbhydrates caused a gain of flesh which continued with but little decrease throughout the experiment and would doubtless have lasted some time longer, a result evidently due to the abundance of non-nitrogenous nutrients and their influence in decreasing the protein consumption.

The experiments of Schulze & Märcker (p. 153), on the other hand, furnish a good example of the opposite effect. In Experiment 6 the fodder consisted of hay and starch; in Experiment 7, of hay and beans. The quantities of digested nutrients per day and head were:

	Protein. Grms.	Carbhy-drates. Grms.	Nutritive ratio.
Experiment 6	30.6	526.7	1 : 17.4
" 7	116.8	570.5	1 : 4.9

Both experiments were on the same two sheep, and the results given are the average of those obtained from both animals. The following table shows the protein consumption and the gain of protein by the body for the last day of the hay and starch fodder, and also for several days on the new ration:

	Protein consumption. Grms.	Gain of protein.* Grms.
April 2	22.6	3.0
" 3 (new fodder)	48.8	63.0
" 4	76.8	35.0
" 5	87.6	24.2
" 6	88.0	23.8
" 7	89.8	22.0
" 14	92.8	19.0
" 21	102 3	9.5

* Exclusive of growth of wool.

Here the change from a poor ration to one rich in protein caused at first a very decided gain of flesh, but one that rapidly decreased, sinking to about a third of its original amount in less than a week and nearly disappearing in nineteen days.

The contrast between this result and that obtained by Kühn & Fleischer is exceedingly instructive, and shows anew the importance of a proper proportion of carbhydrates and fat in the food for the economical production of flesh.

Carbhydrates equivalent to Fat.—It is an important fact for the theory of feeding that the decrease in the protein consumption caused by a given quantity of a carbhydrate is at least equal to, and generally a little greater than that caused by an equal weight of fat.

Formerly, when all the non-nitrogenous substances of the food were supposed to be chiefly valuable as fuel to maintain the vital heat of the body, the relative value of fat and the carbhydrates was naturally measured by the amount of heat which equal weights of the two produced when burned; and it being calculated that one pound of fat produced about 2.5 times as much heat as one pound of sugar or starch, it was assumed that the fat of the food was 2.5 times as valuable as the carbhydrates, and their so-called respiration equivalents were respectively 2.5 and 1. So far as they serve for the production of heat, these numbers may represent their relative value, but, as we have seen, they have other important functions; they not only favor the formation of flesh, but also, as we shall learn, of fat. For the former purpose they are fully equal, weight for weight, to fat, and for the latter much more nearly so than is shown by their respiration equivalents.

The importance of this in the feeding of domestic animals is evident. Fodders containing much fat are comparatively costly, and not only that, but are difficult of digestion by herbivorous animals, and an undue amount of them is liable to produce injurious effects. On the other hand, the carbhydrates are cheap, are contained in large proportions in all the common fodders, and are readily consumed and digested by the herbivora.

These substances in the food of the herbivora effect what the fat does in that of the carnivora: they decrease the protein consumption, and enable the animal to subsist on a much smaller quantity of the costly albuminoids than would otherwise be necessary. It is owing chiefly to the large quantities of them consumed by our domestic animals that they need comparatively little protein when fed for maintenance, and that when fed for production a part of the digested protein is readily deposited in the body as organized protein.

§ 7. Nutritive Value of Amides.

We saw in Chapter II. that a part of the nitrogenous matter of many feeding-stuffs is not true protein, but consists of various bodies, most of which appear to belong to the so-called amide compounds. It becomes, therefore, important to consider the nutritive value of these substances, and all the more important because, until very recently, they have not been considered, or even recognized, in the analysis of feeding-stuffs, and since in many feeding experiments, from whose results important conclusions have been drawn as to the amounts of the various nutrients required in the food of farm animals, feeding-stuffs have been used which have since been shown to contain not inconsiderable amounts of these bodies.

If, as some writers have assumed, they have no nutritive value, we must conclude that our domestic animals require considerably less true protein in their food than has been hitherto thought, while if they have a value in feeding, it is important to know what it is. We shall confine our attention here to the amides, since these are the only non-albuminoid nitrogenous matters which have been experimented on, and the only ones which have yet been found abundantly in the common feeding-stuffs.

It may safely be assumed that these comparatively simple bodies cannot perform all the functions of the albuminoids, but it would seem that certain authors have allowed themselves to be carried too far by purely speculative considerations when they have pronounced them valueless for animal nutrition.

Amides are Decomposed in the Body.—It has been shown by several investigators that amides introduced into the stomach are resorbed, and take part in the chemical changes in the body. Schultzen & Nencki * appear to have been the first to experiment in this direction. They fed a dog, weighing about 16 lbs., with a fixed amount of bread, milk, and water until equilibrium was established between the supply and excretion of nitrogen, and then added to the food various amides. They experimented on acetamide, glycocol, leucin, and tyrosin, and found that all except the first produced a decided increase in the excretion of urea. Acetamide appeared to pass through the system unaltered.

With glycocol the following results were obtained:

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* Zeitschrift für Biologie, VIII., 124.

Date.	Food.	Urea per day. Grms.
September 24	Bread, milk, and water.	3.960
" 25	Same + 15 grms. glycocol.	3.768
" 26	" " "	7.187
" 27	Bread, milk, and water.	9.470
" 28	" " "	3.810
" 29	" " "	3.780

The feeding of glycocol on the 25th and 26th caused a marked increase in the excretion of urea on the 26th and 27th, showing beyond a doubt that glycocol is converted into urea. No glycocol was found in the urine.

The average excretion of urea on the days preceding the glycocol feeding was 3.8285 grammes per day.

Total urea on 26th and 27th	16.657 grms.	
Urea of two average days	7.657 "	
Excess caused by 30 grms. glycocol.	9.000 "	
Urea equivalent to " " "	11.970 "	
Difference	2.970 "	=24.8 per cent.

It will be seen that nearly 25 per cent. of the glycocol fed is unaccounted for. The authors state that the glycocol was not absolutely dry and pure, but it is difficult to imagine that so large an error could be thus caused.

It seems more reasonable to suppose that under the influence of the glycocol a gain of flesh took place, and this supposition is perhaps supported by the fact that the increase in the excretion of urea does not appear till the second day. It would seem as if a gain of flesh took place at first, and that subsequently the protein consumption increased, to fall again when the glycocol was withdrawn.

Such experiments as this, however, are not adapted, as they were not intended, to show the nutritive effect of the substance experimented on.

We have seen that in the dog the addition of protein to the previous food causes but a temporary gain of flesh, while the "protein consumption" is permanently increased, and we should expect that, if amides aided in any way the production of flesh, the effect of a sudden addition of them to the food would be much the same. In an experiment continued for so short a time as this was, the nutritive effect must of necessity be transitory and hard to isolate. At the same time, the above results do not negative the belief that amides are of value as food.

The experiment with leucin gave essentially the same results as the one on glycocol. The leucin was prepared from horn, and was not perfectly pure or dry.

Date.	Food.	Urea per day. Grms.
October 4.	Bread, milk, and water.	4.979
" 5.	Same, + 10 grms. leucin.	5.045
" 6.	" + 30 " "	6.660
" 7.	Bread, milk, and water.	9.098
" 8.	" " " "	4.380
" 9.	" " " "	3.936

The average excretion of urea for the days preceding the feeding with leucin was 4.585 grammes per day.

Total urea on 6th and 7th	15.758	grammes.
Urea of two average days	9.170	"
Excess caused by 40 grammes leucin	6.588	"
Urea equivalent to " " "	9.000	"
Difference (=26.8 per cent.)	2.412	"

An experiment on tyrosin showed that a part of this substance was converted into urea, but that a considerable portion escaped digestion.

Similar experiments by v. Knieriem* on asparaginic acid and asparagin, gave similar results. They showed that these bodies are converted into urea in the animal body, and gave also a deficit of nitrogen, though a smaller one, amounting to 9 to 10 per cent. of the amide nitrogen fed. Further experiments by the same author† on hens, with asparagin, asparaginic acid, glycocol, and leucin, gave also the same result, though with a still smaller deficit of nitrogen. In no case, however, was the excretion in excess of the supply in the food.

Indications of Nutritive Value.—All these results, while highly interesting, leave the question of the nutritive value of amides still in doubt. There are many facts, however, which indicate that they may have a certain value as food. The very fact that they are decomposed in the body is one. Another is, that they are formed from the albuminoids of the food, to a considerable extent, by the action of the trypsin of the pancreatic juice in digestion. It seems hardly probable that the amides thus formed are to be regarded as waste products. Moreover, we have seen that in the plant these bodies may serve as sources of protein, and while such synthetic processes are particularly characteristic of vegetable life, they are by no means excluded in the animal organism.

That, under certain circumstances, an amide may have a high nutritive value, has been strikingly shown by Hermann. It had been shown by Voit and others that gelatin and similar bodies, belonging to the gelatigenous group of compounds (p. 18), are capable of performing the functions of circulatory protein, but cannot serve as a source of organized protein.

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* Zeitschrift für Biologie, X., 279.

† Ibid., XIII., 36.

It was known also that when these bodies were decomposed by acids they yielded essentially the same products as the albuminoids, except that the amide tyrosin was always lacking. Escher,* under Hermann's direction, tried the experiment of feeding a dog with gelatin and tyrosin, and found that the two together could sustain life and cause a production of flesh.

The very probable conjecture has been advanced, that amides in the food may play the same part that gelatin has been shown to do by Voit, viz., take the place of a portion of the circulatory protein, thus leaving the latter available for the formation of flesh or for other productive purposes, and this view seems to be sustained by the experiments about to be described.

Asparagin a Nutrient.—The only experiments as yet executed with the direct purpose of determining the food-value of amides are those of Weiske, Schrodt, and v. Dangel,† at the Proskau Experiment Station, on asparagin. A series of experiments on rabbits and another on hens having shown only that albuminoids could not be entirely replaced by asparagin, but giving in other respects indecisive results, a third series was made on two merino-southdown sheep. The plan of the investigation was as follows: The animals were fed at first with a fodder poor in protein (consisting of hay, starch, and sugar) until the excretion of nitrogen in the urine became constant, and the gain of flesh on this ration was determined. Then, in three following periods, the amount of nitrogen in the daily ration was doubled by the addition respectively of protein (in the form of peas), gelatin, and asparagin, while the amount of non-nitrogenous nutrients remained practically the same. These additions to the original fodder were made in the opposite order in the two cases, in order that the nutritive effect of the asparagin in each sheep might be compared with that of protein in the other, and the influence of individual peculiarities be thus eliminated.

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* Vierteljahrsschrift der naturf. Ges. in Zurich, XXI., 36.

† Zeitschrift für Biologie, XV., 261.

The preliminary feeding was continued in each period until the excretion of nitrogen became constant, and the excrements then collected for five days and analyzed. In the statement of the results which follows, the average per day and head of these five days is given.

PERIOD I.

Ration: Sheep I. and II., 500 grms. hay, 200 grms. starch, 50 grms. sugar.

	Protein digested. Grms.	Carbhydrates digested. Grms.	Fat digested. Grms.	Nitrogen in urine. Grms.	Gain of protein. Grms.
Sheep I..	22.21	412.37	9.89	3.275	1.744
" II.	22.86	412.71	9.67	3.388	0.094

PERIOD II.

Ration: Sheep I., 500 grms. hay, 200 grms. starch, 50 grms. sugar, 42 grms. asparagin; Sheep II., 500 grms. hay, 80 grms. starch, 20 grms. sugar, 250 grms. peas.

	Protein * digested. Grms.	Carbhydrates digested. Grms.	Fat digested. Grms.	Nitrogen in urine. Grms.	Gain of protein. Grms.
Sheep I..	70.86	411.25	9.87	9.958	8.625
" II.	83.54	427.49	14.08	11.099	15.169

* See Note on opposite page.

Period III.

Ration: Sheep I. and II., 500 grms hay, 200 grms. starch, 50 grms. sugar, 53 grms. gelatin.

	Protein * digested. Grms.	Carbhydrates digested. Grms.	Fat digested. Grms.	Nitrogen in urine. Grms.	Gain of protein. Grms.
Sheep I..	66.68	399.71	9.23	8.69	12.375
" II.	66.38	401.52	8.86	9.95	4.250

Period IV.

Ration: Sheep I., 500 grms. hay, 115 grms. starch, 15 grms. sugar, 200 grms. peas; Sheep II., 500 grms. hay, 200 grms. starch, 50 grms. sugar, 53 grms. asparagin.

	Protein * digested. Grms.	Carbhydrates digested. Grms.	Fat digested. Grms.	Nitrogen in urine. Grms.	Gain of protein. Grms.
Sheep I..	71.24	441.17	13.34	9.730	10.425
" II.	84.03	421.03	9.77	11.497	12.175

Determinations of sulphur were made in all the experiments, and showed that in every case but one (Sheep II. in Period III.) a gain of this element also took place.

These results show, beyond all reasonable doubt, that asparagin, at least, is really a nutrient, and that when added to a fodder poor in albuminoids it may cause a gain of protein by the body, just as we have already seen that the albuminoids may.

It probably acts in the way already suggested, viz., by taking the place of a part of the circulatory protein and

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* To render the results better comparable, the nitrogen of the asparagin and gelatin has in all cases been multiplied by 6.25 and counted as protein.

protecting it from destruction. That this is so is perhaps indicated by the fact that a gain of sulphur also took place. All the albuminoids contain this element, while asparagin is free from it, and hence we may conclude that the protein deposited in the body was derived from the albuminoids of the food, and was not formed by a synthetical process from the asparagin.

An important point is that the gain produced by asparagin was nearly as great as that produced by an equivalent amount of albuminoids. From this it would appear that while asparagin cannot alone supply material for the formation of protein in the body, it is fully capable of performing the functions of the so-called circulatory protein, so far as the production of flesh is concerned, and for this purpose is practically just as valuable as protein for increasing the richness of a ration already containing a reasonable amount of that substance. This suggests the question whether much of the so-called circulatory protein of the body may not be simply that portion of the protein of the food which is converted into amides by the action of trypsin and other ferments during digestion. The supposition seems quite plausible, and is certainly interesting from a physiological standpoint, though of little practical importance for the purposes of cattle-feeding.

Other Amides.—Whether what Weiske has shown regarding asparagin is true of other amides as well, can, of course, be finally decided only by direct experiment; but in the meantime, while we must beware of drawing too general conclusions from a single experiment, it seems highly probable that at least those other amides which have been shown to be convertible into urea in the body may contribute to nourish it.

But, if this be true, it also follows that these bodies as they occur in fodders, *i. e.*, associated with comparatively large quantities of protein, are practically just as valuable for the production of flesh as the latter, since, when feeding-stuffs containing them are used, we have essentially the conditions of Weiske's experiments, viz., amides added to a fodder containing considerable true protein, and should expect the same results. The importance of this fact is easily seen. If, for practical purposes, amides are equivalent to protein, it is unnecessary to consider them separately in the formation of feeding standards, while substitution of a part of the protein called for by a feeding standard by amides will cause no decrease in the nutritive value of a ration, *so far as the production of flesh is concerned.* None of the experiments yet made touch the question of the effect of amides on fat production. It may well be the case that they cannot play the important part in this process which the albuminoids appear to, and, on the other hand, it is quite possible that they, like the carbhydrates, may protect the fat of the body from oxidation.

Speculation in advance of experiment is fruitless; but, meanwhile, though the study of the nutritive value of these bodies has but just begun, all the results yet reached warn us against hastily declaring them worthless or the results of chemical analysis of feeding-stuffs false and misleading.

§ 8. EFFECT OF QUANTITY OF FOOD.

A Large Amount of Fodder Causes a Relatively Larger Gain.—It is self-evident that a large quantity of fodder of the same composition must cause a greater deposition of flesh in the body than a small one; but the gain is not only absolutely, but relatively greater, as is shown by numerous experiments made on oxen, at Weende, by Henneberg & Stohmann. In one case, *e. g.*, the total quantity of the digestible nutrients in the daily fodder was increased from 17.86 to 19.46 pounds, while the ratio between the digestible albuminoids and the non-nitrogenous nutrients (the nutritive ratio) remained the same.

The result was that, after the increase, 32 per cent. of the total quantity of digested albuminoids was deposited as flesh, while before only 18 per cent. had been. The absolute quantities were 1.19 and 0.62 pounds. In other trials, on a ration consisting exclusively of clover-hay, an increase of four or five pounds per day and head in the hay ration caused the amount of protein deposited as flesh to increase from 9 per cent. to 14 per cent., and in another experiment from 11 per cent. to 15 per cent. of the total digested protein of the fodder. That is, out of every hundred pounds of digested protein the animals converted into flesh, on the smaller ration, 9 and 11 pounds, on the larger, 14 and 15 pounds. These facts show how exceedingly important it is, especially in fattening, to stimulate the animals to the largest possible consumption of fodder consistent with health; a little more or less may produce an essentially different effect, showing itself perceptibly in a more or less rapid increase of the live weight.

CHAPTER VII.

THE FORMATION OF FAT.

§ 1. Sources of Fat.

The Fat of the Food, when digested and resorbed, may remain undestroyed under suitable conditions, and be stored up in the body; this is now as certain as that a formation of fat from other constituents of the food may also take place. We will, on this point, only refer to the results of some of the later experiments, which, like many on the laws of flesh formation, we owe to the activity of the Physiological Institute at Munich.

Carnivorous animals which, by a previous feeding with meat exclusively, have become rich in flesh and comparatively poor in fat, can be easily made quite fat-free by long fasting; the time when the minimum of fat remains is easily recognized from the fact that the excretion of úrea, which during hunger is very constant, at last increases quite suddenly, because with the entire disappearance of the fat more protein is consumed in the body. Such an animal, a dog weighing about 20 kilogrammes, after thirty days of fasting, was fed for five days with the greatest possible quantities of pure fat, of which, on an average, 370.8 grammes daily were digested. This is such a large quantity that it is impossible to suppose it to have been completely oxidized in the body, for then 1,040 grammes of carbonic acid should have been excreted daily, while direct determinations of the respiratory products of dogs twice as large and in the best condition give much smaller numbers.

In the body of the animal, which was killed at the end of the experiment, 1,352.7 grammes of fat were found on the various organs, instead of the 150 grammes which, according to other investigations, was the greatest amount that could have been present in the body after thirty days' fasting, so that in this case about 250 grammes daily of the fat of the food remained undestroyed and were deposited in the body. In numerous other experiments on dogs, too, with a more normal food of meat and fat, and with help of the respiration apparatus, the fact has been confirmed that often a very considerable part of the fat of the food may be retained in the body.

The fat, however, must be analogous to the animal fats or easily altered into them, since entirely foreign fats are either not resorbed from the alimentary canal at all or are rapidly oxidized. This does not, of course, prevent the fat in the fodder of the herbivora from contributing directly to the deposition of fat in the body, since most of the vegetable fats are very similar in their composition and properties to the animal fats.

Formation of Fat in the Body.—For the fact of the formation of fat in the body from other substances no special proofs need be adduced; it is sufficiently evident from daily experience, especially in fattening and in milk-production.

But it is of importance to consider the question what nutrients yield chiefly or exclusively the necessary material for the formation of fat.

Naturally only the albuminoids and carbhydrates are to be considered in this connection, for besides these nutrients and the fat itself, there are no other organic substances present in such quantity in the fodder, either of the herbivora or carnivora, as to be able to contribute, in any essential degree, to fat-formation.

Formation of Fat from Albuminoids.—That fat can be formed from the albuminoids is now denied by no one acquainted with the subject.

The fact that the albuminoids in decay, and on treatment with alkalies and with oxidizing agents, form various fatty substances along with other products of decomposition, favors this view. It has also been observed, that in the milk of the same cow the quantity of albuminoids frequently decreases when that of the fat increases, and the reverse. The occasionally observed formation of so-called adipocere also favors this view; almost all the nitrogenous substances of the body disappear, and in place of the muscles, etc., appears a waxy-looking, fatty mass, soluble in ether. Somewhat similar is the fatty degeneration of the muscles and other organs of the living body in certain diseases and not seldom in excessive fattening, of swine, *e. g.* This fatty degeneration of almost all the organs of the body is especially marked in phosphorus poisoning, and, according to observations made in Munich, it cannot be doubted that fat in this case arises exclusively from the albuminoids, urea being separated from the latter and excreted. Two apparently independent alterations of the tissue metamorphosis appear to occur at the same time; first, an increased protein consumption, resulting in the production of urea and fat, and second, a diminished absorption of oxygen by the blood and consequently a decreased oxidation of the fat, both processes working together to cause a large deposition of fat in the body. For example, the liver of a man who died of phosphorus poisoning contained in its dry substance the enormous amount of 76.8 per cent. of fat.

If a doubt still remained as to the formation of fat from albuminoids, it must disappear on a consideration of the results which have been obtained on healthy animals with an entirely normal food. For example, the eggs of ordinary flies have been allowed to develop on pure blood and from seven to eleven times as much fat found in the larvæ as was originally contained in eggs and blood together, although the animals had not consumed nearly all the blood; the excess of fat could only have come from the albuminoids of the food.

Yet more important, however, are the numerous experiments made by feeding dogs on large quantities of pure (fat-free) meat.

The three following experiments by Voit & Pettenkofer * may serve as an example. In these experiments the respiration apparatus was used, and hence the excretion of carbon, as well as of nitrogen, could be determined:

	Fifth day of feeding with 1,800 grms. meat.		Second day of feeding with 2,500 grms. meat.		First day of feeding with 2,000 grms. meat.	
	Nitrogen. Grms.	Carbon. Grms.	Nitrogen. Grms.	Carbon. Grms.	Nitrogen. Grms.	Carbon. Grms.
Fed	61.20	225.4	85.00	313.0	68.0	250.4
Excreted in Urine	59.10	35.6	84.38	50.6	66.5	40.0
Dung	0.60	4.3	1.00	6.7	0.8	5.4
Respiration	....	179.0	....	213.6	....	158.3
Total excretion	59.70	218.9	85.38	270.9	67.3	203.7
Gain (+) or Loss (–).	+1.50	+6.5	–0.38	+42.1	+0.7	+46.7

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* Zeitschrift f. Biologie, VII., 433.

In the second and third experiments especially, while there is no essential gain or loss of nitrogen, there is a gain of carbon by the body larger than any possible experimental error, and which must be interpreted, according to the principles of Chapter V., as showing a production of fat in the body, and that this fat must have been produced from albuminoids is self-evident. In the first experiment the feeding had continued four days, and there the gain of carbon is small, indicating that a gain of fat produced by albuminoids alone does not continue long, a fact which other results confirm. Many other similar experiments showing a formation of fat from albuminoids might be adduced.

Fat from Carbhydrates.—Whether fat can be formed from carbhydrates is still a disputed question. According to Voit & Pettenkofer the protein of the body in decomposing takes up the elements of water and splits up into urea and a fat-like substance; and, as stated on page 88, it has been calculated that 100 parts of protein and 12.3 parts of water, contain the elements of 33.5 parts of urea, 27.4 parts of carbonic acid, and 51.4 parts of fat.

They have shown, in experiments shortly to be described, that the carbhydrates of the food are more easily oxidized in the system than the fat of the food or the fat formed from the albuminoids, and that they protect the latter two from oxidation and thus indirectly aid the formation of fat. Having also shown, by experiments like those just adduced, the possibility of the production of fat from protein, they naturally regard the latter, together with the fat of the food, as the chief sources of fat under all circumstances, and consider the action of the carbhydrates to be simply protective.

According to this view the carbhydrates would, at most, serve for the production of fat only when the protein and fat of the food were exhausted, or, in other words, when the supply of oxygen in the body was not sufficient to consume all the carbhydrates. If we find that, in all experiments on fattening, the digestible protein and fat of the food are sufficient to account for the amount of flesh and fat actually produced, we shall have very strong presumptive evidence that the views of Voit & Pettenkofer and their followers are correct, though, of course, such evidence is of a negative character and can never reach absolute proof. If, on the other hand, we find that, in accurately conducted experiments, the digestible protein and fat of the food do not suffice to account for the flesh and fat produced within the limits of experimental error, we have a proof that the carbhydrates of the food must have contributed to its formation to the extent, at least, of the observed difference.

Experiments on Ruminants.—Unfortunately there have been as yet no extensive investigations in which the fat-production of domestic animals, or of any herbivorous animals, under the influence of a definite and suitable ration, has been determined with scientific accuracy, *i. e.*, by careful determination of all the solid, liquid, and gaseous excretions.

In considering this question, we can avail ourselves only of the results of so-called "practical" experiments, in which the nutritive effect of the fodder has been determined simply by the increase of the live weight of the animal, or perhaps from the dressed weight, or at best from experiments in which the "sensible" (solid and liquid) but not the gaseous excretions have been accurately determined.

Milk-fat.—In regard to the production of milk-fat by cows we have three investigations, carried out respectively by Voit* in Munich, E. v. Wolff† in Hohenheim, and G. Kühn and M. Fleischer‡ in Möckern.

In the first a rich fodder was given, in the two others, on the contrary, one less rich in albuminoids.

In the following table the sum of the fat of the fodder and the fat which might have been formed from the protein of the latter (51.4 per cent. of the protein consumption) is compared with the amount actually found in the milk. The numbers are grammes per day and head :

	Fat of fodder. Grms.	Fat from protein. Grms.	Total. Grms.	Fat of the milk. Grms.
Munich, Experiment *a*......	318.8	401.8	720.6	577.5
" " *b*......	276.0	308.5	584.5	337.3
Hohenheim, " I......	170.5	160.1	330.6	303.3
" " II......	166.5	171.3	337.8	290.5
Möckern, " I.....	183.5	79.5	263.0	277.5
" " II......	183.5	69.5	253.0	292.0

In the Munich and Hohenheim experiments, the fat available from the two sources named was more than sufficient to account for that produced in the milk. In Möckern, on the contrary, a small excess of milk-fat was found; but even if this excess had been considerably greater, no definite conclusions in regard to its source could be drawn. Equilibrium between the supply and excretion of nitrogen was, indeed, established in the Möckern experiments, as in all the others, but whether the animals were also in equilibrium as to carbon or whether the fat of the body took part in the milk-production, as is so often the case with milk cows, even when well fed, could only have been decided with certainty by the help of a respiration apparatus.

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* Zeit. f. Biologie, 1869, p. 113.

† Ernährung Landw. Nutzthiere, 349.

‡ Landw. V. St., XII., 451.

Experiments on Fattening.—Something more definite as to the source of animal fat may perhaps be learned from the results of fattening experiments on domestic animals, if we at the same time consider that, according to the experiments of Lawes and Gilbert in England (see p. 9), the increase of the live weight in fattening has the following composition in 100 parts:

	Ash.	Protein.	Fat.	Total dry matter.	Water.
Swine..........	0.06	6.44	71.5	78.0	22.0
Sheep..........	2.34	7.13	70.4	79.9	20.1
Oxen...........	1.47	7.69	66.2	75.4	24.6
Average.....	1.45	7.53	66.6	75.6	24.4

Of late years a large number of fattening experiments have been executed at the various Experiment Stations, especially with sheep. In these experiments the fodder has been analyzed according to the same methods, the actual increase of weight determined as accurately as possible, and the duration of the experiments made sufficiently long (from two and one-half to fully three months) to nullify, to a large extent, the effects of any temporary variations of the live-weight which might occur.

If, now, in these experiments, we assume that, according to Lawes & Gilbert's results, 70.4 per cent. of the gain made consists of fat, we shall have a basis for computing whether the available protein and fat of the food consumed were sufficient to account for the amount of fat actually produced. Obviously, such computations are simply approximate, but at the same time their results have a certain value when derived from a large number of experiments.

This comparison has been made by the writer in seventy-seven different experiments, viz., fourteen by Henneberg, in Weende, in 1858–63;* six by Stohman, in 1862–63,† and eight in 1864–65,‡ at Brunswick; nine by E. v. Wolff, in 1870–71,§ and ten in 1871–72,‖ at Hohenheim; nine by Henneberg & Stohmann;¶ eight by Haubner & Hofmeister, in Dresden; and twelve by F. Krocker, in Proskau.**

Each one hundred parts of protein oxidized in the body was considered to have yielded 51.4 parts of fat, and to this amount was added the ready-formed fat of the fodder.

The result, with one or possibly two exceptions, was that in all cases the protein and fat were sufficient to account for the amount of fat formed, although in some of the experiments little margin was left.

E. v. Wolff has separated fifty-nine of these experiments into four groups, according to the amount of digestible protein contained in the fodder, with the following results in pounds per day and head:

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* Jour. f. Landw., 1858, p. 362; 1860, p. 1; 1866, p. 303.

† Ibid., 1865, 2 Supplement.

‡ Ibid., 1867, p. 133.

§ Landw. Jahrb., I., 533.

‖ Ibid., II., 221.

¶ Jour. f. Landw., 1865, Supplement.

** Preuss. Ann. d. Landw., 1869, Sept. and Dec.

No. of Experiments.	Digested per Day and Head. Average.		Nutritive ratio.	Increase of live-weight per day and head. Lbs.
	Albuminoids. Lbs.	Non-nitrogenous nutrients. Lbs.		
7	0.220	1.648	1 : 7.49	0.111
13	0.268	1.557	1 : 5.81	0.158
20	0.329	1.588	1 : 4.70	0.189
19	0.384	1.538	1 : 4.01	0.206

These numbers speak very decidedly for the favorable action of the albuminoids on the fat production ; a greater increase of weight of the animal accompanies a greater supply of albuminoids, while the quantity of the non-nitrogenous nutrients is nearly the same in all the groups, and therefore can have exerted no essential influence on the increase of weight.

If we take into account, however, the fact that, in all probability, some of the so-called protein in these experiments was really not protein, but amides or similar bodies, which, though they may aid the flesh production, can hardly serve as a source of fat, the number of cases which indicate a formation of fat from carbhydrates will probably be considerably increased.

Still more decided results pointing toward a direct participation of the carbhydrates in the production of fat were obtained in the experiments of Henneberg, Kern, and Wattenberg,* already referred to for another purpose in Chapter I.

In this investigation two sheep were killed at the beginning of the experiment, and the amount of the various components of their bodies (flesh, fat, bones, tendons, etc.) determined as accurately as possible, while two similar sheep were examined in the same way after having been fattened for several months.

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* Jour. f. Landw., Jahrg. 26, p. 549.

The experimenters themselves did not consider the question of the origin of the fat, but E. v. Wolff * has shown from their results that a portion of it must have been formed from carbhydrates.

The carcases of the unfattened and fattened animals had the following composition:

	Dry and fat-free flesh. Grms.	Dry fat. Grms.	Fresh bones. Grms.	Fresh tendons. Grms.
Unfattened................	2,465	5,406	2,530	2,488
Fattened..................	2,485	15,077	2,566	1,818
Difference................	+20	+9,671	+36	−670

The result of the fattening was almost wholly a gain of fat.

The gain of 9,671 grms. of fat does not include the fat of the wool nor the small quantities contained in skin, head, legs, etc., etc., which would probably have amounted to 200 grms. more. This, however, we will leave out of the account.

During the time of the experiment the animals digested about 9,490 grms. of protein and 2,554 grms. of crude fat (ether extract). Assuming that the digested ether extract produced an equal amount of fat, which is hardly proba-

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* Landw. Jahrb., VIII., I. Supplement, p. 269.

ble, and also that the digested protein yielded 51.4 per cent. of its weight of fat, we obtain the following numbers:

		Grms.
Fat actually gained		9,671
Fat from ether extract	2,554 grms.	
" " protein (9,490 × 0.514)	4,878 "	
Total		7,432
Fat unaccounted for		2,239

It thus appears that *at least* 2,239 grms. of fat must have been produced from carbhydrates. In reality the amount was considerably greater, however. Not only have we not taken into account the fat of the offal, but the amount of protein available for the formation of fat is less than appears above. In the first place, a considerable growth of wool took place, demanding, of course, a supply of protein, and in the second place, one of the feeding-stuffs used (lucerne hay) has been shown by Kellner * to contain a considerable proportion of amides, which were here reckoned as albuminoids.

These results indicate, most decidedly, that in these experiments a considerable amount of fat was formed from some other materials of the food than fat or protein.

Experiments on Swine.—Nearly or quite all the experiments which have been made on swine have yielded results favorable to the belief in the formation of fat from carbhydrates.

The earliest investigations were those of Lawes & Gilbert, in 1850, which, on the assumption that the increase in the live weight had the composition determined by them in other experiments (see pp. 9 and 176), showed, in many cases, a greater gain of fat than could be accounted for by the protein and fat of the food.

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* Landw. Jahrb., VIII., I. Supplement, p. 243.

Later experiments have given similar and even more decided results. An increase of 100 pounds in the live-weight has frequently been obtained with a fodder containing 10 to 15 lbs. of fat and 50 to 70 lbs. of protein. In one case the above gain was made on a fodder containing only 40.8 lbs. of protein and 6.8 lbs. of fat, while the weight of the animals increased from 70.5 lbs. at the beginning of the experiment to 246.5 lbs. at its close. These results appear almost incomprehensible unless we admit a production of fat from carbhydrates.

Weiske & Wildt,* in Proskau, have attempted to solve the problem by experiments on the same plan as those of Henneberg, Kern & Wattenberg on sheep. Of four six-weeks-old pigs, two were killed at the beginning of the experiment, and the total quantity of flesh and fat in their bodies was determined. Of the other two, one received a fodder rather poor in protein for 184 days. The second, which was to have been fed with a fodder rich in protein, became sick, and was therefore excluded from the experiment.

At the close of the feeding, the sound animal was killed and the flesh and fat present in his body determined, as in the two other animals at the beginning of the experiment.

On the assumption, now, that the first two pigs had, at the time they were killed, the same composition as the one which was fattened, we have only to subtract the average of the former from the latter to find the amount of flesh and fat produced during the feeding.

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* Zeitschrift für Biologie, X., 1.

	Protein. Kilos.	Fat. Kilos.
Fattened	2.2835	7.0138
Unfattened	1.0410	0.8740
Produced	1.2425	6.1398
Digested from food	14.3244	0.5748
Fat formed in body		5.5650
Protein available for fat formation	13.0819	
Available protein × 0.514 =		6.7241

According to these figures, the protein and fat of the food were sufficient to cover the amount of fat produced.

Various circumstances, however, unite to lessen the value of the result reached. From some cause, the growth of the animal was unusually slow. Furthermore, the fodder used consisted of potatoes, rye bran, and starch, and at the time when this research was made the presence of amides in potatoes had not been discovered. Since then from 26.8 to 39.9 per cent. of the total nitrogen of potatoes has been found in various experiments to exist in the form of amides, and if we take this fact into account, the above calculation yields very different results.

Out of the total digested protein, 11.1227 kilos. came from the potatoes. Assuming 26.8 per cent. of this to be amides, there remain 8.1419 kilos., making, with 3.2017 kilos. from the bran, a total of 11.3436 kilos. of true protein digested.*

The figures then stand as follows:

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* On the assumption that protein and amides were digested to the same extent. It is more than probable that the amides were wholly digestible, which would give a still greater deduction.

	Protein. Kilos.	Fat. Kilos.
Produced	1.2425	6.1398
From food	11.3436	0.5748
Fat formed in body		5.5650
Protein available for fat production	10.1011	
Available protein × 0.514 =	....	5.1920

The result is exactly the opposite of that previously obtained. The difference is too small to prove a formation of fat from carbhydrates, more especially as a participation of the amides in fat-building is not altogether impossible, but it deprives the experiment of all value as a proof that carbhydrates do not furnish material for fat.

Some late feeding experiments on swine by E. v. Wolff,* at Hohenheim, have also given results which seem to show quite plainly a formation of fat from carbhydrates. A gain of 100 pounds was made from an amount of fodder containing from 47.1 to 71.4 lbs. of digestible protein, and from 1.6 to 3.5 lbs. of digestible fat. The larger of these quantities could yield, at most, 40.2 lbs. of fat, while, according to Lawes & Gilbert, 100 lbs. increase would contain at least 70 lbs. of fat.

Experiments on Dogs.—In regard to the dog, we can assert that in no case is the assumption of a formation of fat from carbhydrates necessary. As has already been mentioned, large quantities of fat may be deposited in the body from the fat or the albuminoids of the food; but in twenty-two respiration experiments made by Pettenkofer & Voit, the fat deposited in the body was always fully accounted for by that which could be formed from the amount of albuminoids decomposed in the body, and was proportional not to the carbhydrates but to the albuminoids of the food. With the same quantity of albuminoids in the food, an increase of the carbhydrates caused no increase in the amount of fat formed, but only an increased excretion of carbonic acid, showing that the carbhydrates were rapidly oxidized in the blood.* On the other hand, an increase in the albuminoids of the food—the quantity of carbhydrates remaining the same—caused a very considerable increase in the amount of fat produced, thus showing an intimate connection between the supply of protein in the food and the formation of fat in the body.

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* Landw. Jahrbücher, VIII., I. Supplement, 238.

Sources of Uncertainty.—Having considered the experimental evidence bearing on the question of the sources of animal fat, it now becomes necessary to consider briefly how much weight attaches to this evidence.

It must be admitted at once that the data now at our command are not sufficient to enable us to solve the problem. No thorough and accurate scientific study of the subject has yet been made, if we except Pettenkofer & Voit's experiments on dogs. The conclusions drawn in the preceding paragraphs from experiments on farm animals are to be regarded only as very probable, not as certain.

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* It should be said that, according to Zuntz (*Landw. Jahrbücher*, VIII., 94), carbhydrates cause no increase in the excretion of carbonic acid *when introduced directly into the blood*, but only when taken into the alimentary canal. According to him, the increased excretion of carbonic acid is caused by the excitation of the nerves of the stomach and intestines. In a practical point of view, however, the result is much the same, since the carbhydrates of the food must be taken into the alimentary canal, and it makes little difference whether the carbonic acid is produced from them or from the tissues of the body.

In the first place, we do not know how much fat was actually formed in these experiments.

The estimates of its amount, based on the composition of the increase of fattening animals as determined by Lawes & Gilbert, are obviously very uncertain; and even in such experiments as those of Henneberg, Kern & Wattenberg, and of Weiske & Wildt, it is highly improbable that the animals killed and analyzed at the beginning of the experiments had *exactly* the composition of those reserved to be fattened, and we have no means of judging of the amount of the difference.

Again, in all cases we have assumed that 100 parts of protein decomposed in the body gave rise to 51.4 parts of fat.

Now this number is a purely theoretical one, based on a calculation by Henneberg of the greatest amount of fat which could possibly be formed from a given weight of protein; and, while there can be no doubt that fat is formed from protein, it is very doubtful whether this maximum amount is formed in every, or even in any, case. It is a commonly observed fact that when a chemical compound breaks up into simpler bodies, some of its latent energy is set free, either as heat or in some other form. Zuntz (*loc. cit.*, p. 96) has, however, shown that such a formation of fat and urea from protein as we have been supposing, is only possible on the condition that the resulting products contain all the latent energy of the decomposed protein, and that none is given off in the decomposition. This, Zuntz remarks, is a process wholly without analogy in the animal body, where all decompositions are accompanied by the setting free of considerable quantities of heat. Without laying too much stress upon this point, we must still admit its importance.

If Zuntz's ground be well taken, then it would appear that in all the calculations on this subject we must reduce the amount of fat obtainable from the protein of the food, leaving still more to be formed from other nutrients.

Conclusions.—The following conclusions regarding the sources of animal fat appear to be justified by our present knowledge on the subject:

1st. Animal fat may be formed from the fat of the food.

2d. It may be formed from the protein of the food.

3d. Assuming the accuracy of the factor 0.514 for the conversion of protein into fat, the amount of fat produced by the dog is covered by the protein and fat of the food.

4th. Ruminants have in some cases produced less, and in some cases more, fat than could be accounted for by the protein and fat of the fodder.

5th. Swine have, in the majority of cases, produced more fat than could have been formed from the protein and fat of the food.

When we consider the fact that the proofs of the formation of fat exclusively from protein are essentially negative in their nature, while those of its formation from carbhydrates are direct, it would seem that we must admit that the carbhydrates may serve as a source of fat to swine, and also, under some circumstances at least, to herbivora. This, however, is equivalent to admitting it for all animals, since there are no essential differences known in the nutritive processes of the higher animals.

With our present imperfect knowledge, we must regard both protein and carbhydrates as sources of fat, while the final settlement of the question, as well as the determination of the part played by each, must be left to the decision of more exact experiments.

Having thus considered at some length the important question of the sources of animal fat, we are prepared to take up the general laws which regulate its formation. It is evident, however, that until we know with certainty the source from whence the fat of the body is derived, our attempts to formulate the laws of its production must be more or less tentative. Most of our knowledge upon this subject is due to the labors of Pettenkofer & Voit at Munich. These investigators hold that fat is not formed from carbhydrates in the body, and their experiments, which were made before many of the facts spoken of in the preceding paragraphs were known, are interpreted in accordance with that belief. If we add to this fact the great labor involved in investigations of this kind, the use of the complicated respiration apparatus being essential, we can readily understand why our knowledge of the laws of the formation of fat should be in some respects unsatisfactory. At the same time, what is already known is very valuable and offers important aid to the formation of a rational theory of feeding.

§ 2. Feeding with Fat Alone.

The Fat of the Food protects the Body-fat.—In Pettenkofer & Voit's experiments* a dog was in one case allowed to fast for eight days, and in a second experiment was fed daily with 100 grammes of pure fat, about the amount which was found to have been oxidized daily in the first experiment.. On the eighth day the following results were obtained :

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* Zeitschrift f. Biologie, V., 369.

	Grms.	Grms.
Fat eaten per day..............	100	0
Consumption of flesh in body....	159	138
" " fat* "	111	114
Gain (+) or loss (−) of fat......	+6	−99

While, as we have already learned, fat does not hinder the protein-consumption in the body but rather tends to increase it, when fed alone, the loss of fat is entirely stopped by a quantity equal to that lost in hunger. That is, an increased supply of fat does not, like an increase of albuminoids, augment the consumption, but takes the place of that before consumed, pound for pound.

The simplest way of explaining this is by the assumption that the fat of the food is more easily oxidized than that already deposited in the body, and that the former therefore possesses itself of the oxygen of the blood and protects the latter from oxidation.

A Gain of Fat may accompany a Loss of Flesh.—In another experiment, in which a large quantity (350 grammes daily) of fat was fed, the loss of flesh on the second day amounted to 227 grammes, and at the same time 186 grammes of fat were retained in the body. The same fact is shown by the second experiment on p. 172.

§ 3. FEEDING WITH PROTEIN ALONE.

Protein can protect the Fat of the Body from Oxidation.—The following experiments by Pettenkofer & Voit,[†] on a dog fed exclusively with meat, were made with the help of the respiration apparatus:

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[*] Including that formed from protein.

[†] Zeitschrift f. Biologie, VII., 489.

Meat fed. Grms.	Flesh consumed in body. Grms.	Gain (+) or loss (−) of flesh. Grms.	Gain (+) or loss (−) of fat. Grms.
0	165	−165	−95
500	599	−99	−47
1,000	1 079	−79	−19
1,500	1,500	0	+4
1,800	1,757	+43	+1
2,000	2,044	−44	+58
2,500	2,512	−12	+57

While with a small ration of meat the animal lost both flesh and fat, a medium ration (1,500 grammes) sufficed to stop the loss, not only of flesh but also of fat, and larger amounts, while they could not, for the reasons explained in the preceding chapter, cause any considerable gain of flesh, did cause a gain of fat; *i. e.*, not only did the albuminoids protect the body-fat from oxidation, but new fat was formed from them and laid up in the body.

These results are most simply explained by the assumption that the fat formed in the body from albuminoids, like that contained as such in the food, is more readily oxidized than that already stored up in the body.

Incidentally these experiments give proof of the possibility of the formation of fat from protein, and also of the statement just made that a gain of fat may accompany a loss of flesh.

§ 4. Feeding with Protein and Fat.

Protein protects the Fat of the Food from Oxidation.—Since in the fodder of herbivorous animals fat is usually present in small quantity, and is of comparatively little importance, it will be sufficient to indicate in outline the general results of experiments on carnivorous animals. It has already been shown that fat is produced in the body in the decomposition of albuminoids, and that with a comparatively large amount of the latter the fat thus formed may equal the amount oxidized in the body.

If, now, to such a ration we add a certain quantity of fat, say 100 grammes, we have just so much more fat available for deposition in the body, since the consumption of fat does not increase with the supply as does that of the albuminoids.

Thus, in a series of experiments made by Pettenkofer & Voit,* a dog was fed daily 1,500 grammes of meat, a quantity which had been found sufficient to keep him in equilibrium both as regards flesh and fat, and received also varying quantities of fat.

Food.		Effect on Body.			
Meat. Grms.	Fat. Grms.	Consumption of flesh. Grms.	Gain of flesh. Grms.	Consumption of fat.† Grms.	Gain of fat. Grms.
1,500	30	1,457	+43	158	32
1,500	60	1,501	– 1	186	39
1,500	100	1,402	+98	163	91
1,500	100	1,451	+49	151	109
1,500	150	1,455	+45	174	136

The addition of fat caused a deposition of it in the body, and the amount thus laid up was, in nearly every case, proportional to that fed.

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* Zeitschrift f. Biologie, IX., 30.

† Including the fat produced from protein.

That is, the amount of fat yielded by the decomposition of the albuminoids was sufficient to supply what was needed for the vital processes, and the extra amount added was stored up in the body. This is generally expressed by saying that the fat produced from the albuminoids is more easily oxidized than that of the food, or, in other words, that the protein protects the fat from oxidation, but there seems to be no absolute proof that such is the case. There is simply an excess of fat present over that required, and this excess is laid up against future needs. The fat produced from the albuminoids is always to be added to that given in the food in estimating the effect of a fodder. If much protein is fed, the protein consumption in the body will be great, and while little or no organized protein is produced, large quantities of fat may be laid on. A too great accumulation of circulatory protein, however, is to be avoided, since it increases the rapidity of the circulation of fluids in the tissues, and tends to produce a more rapid oxidation.

§ 5. Feeding with Protein and Carbhydrates.

The only really scientific experiments on this point are by Pettenkofer & Voit,* who, as we have seen, do not believe in the possibility of a formation of fat from carbhydrates. The experiments and results now to be given form a powerful argument in favor of the correctness of their view in its application to the animal experimented on. At the same time we must not forget that other experiments strongly indicate that, in some cases, fat is formed directly from carbhydrates.

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* Zeitschrift f. Biologie, IX., 435.

Carbhydrates may be Oxidized instead of Fat.—By the addition of carbhydrates to albuminoid food the protein consumption is, indeed, somewhat decreased, but never stopped; but the carbhydrates, when present in sufficient quantity, may protect entirely from oxidation the fat of the body, and also the fat of the food and that formed from protein. This effect of the carbhydrates becomes evident when we compare some of the experiments in which the animal was fed on meat alone with those in which the same quantity of meat was fed with the addition of starch or sugar.

FOOD.			NUTRITIVE EFFECT.			
Meat. Grms.	Starch or sugar. Grms.	Fat. Grms.	Consumption of flesh. Grms.	Loss of flesh. Grms.	Consumption of fat.* Grms.	Gain of fat. Grms.
500	...	..	599	99	108	– 47
500	167	6	530	30	50	+ 14
500	182	..	537	37	43	+ 16

The carbhydrates of the food in the second and third experiments caused the fat consumption to decrease to less than half its former amount and made a corresponding gain of fat possible. This they apparently accomplished by possessing themselves of the oxygen which otherwise would have combined with the fat; in other words, they were oxidized in place of the latter.

Difference in the Action of Carbhydrates and Fat.—Pettenkofer & Voit have found that while an increase of fat in the food causes an increased deposition of fat in the body, an increase of the carbhydrates does this only up to a certain limit. For example, if fat be fed to a fasting animal in more than sufficient quantity to supply the necessary consumption, the excess is deposited in the body, and the more fat is fed the more is thus deposited. If carbhydrates be fed in this way, they are oxidized in the blood, and a corresponding quantity of the body-fat and of that produced from the decomposition of the albuminoids of the body is protected from destruction. If enough carbhydrates are fed, *all* the fat separated from the protein may be deposited as body-fat. Thus far the action is essentially like that of fat, but *if we increase the carbhydrates beyond this point we get no further laying on of fat.* The quantity of fat deposited in the body under such circumstances is found to be proportional to the amount of the protein consumption, and the excess of carbhydrates is simply burned up, producing an increased excretion of carbonic acid.* Essentially the same results were obtained when carbhydrates were fed along with albuminoids. In no case was the gain of fat greater than corresponded to the ready-formed fat of the food and that which could be produced from the albuminoids, and any excess of carbhydrates over that required to protect this amount of fat from oxidation produced no effect except an increased excretion of carbonic acid.

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* Including that formed from protein.

On the other hand, it has been observed that when a large quantity of carbhydrates are fed, and the albuminoids are gradually increased, the gain of fat also increases.

The following experiments illustrate this:

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* See foot-note, p. 184.

Carbhydrates (starch) of food. Grms.	Meat of food. Grms.	Flesh consumption. Grms.	Gain of fat. Grms.
379	....	211	41
379	800	608	69
379	1,800	1,469	122

The increased oxidation of albuminoids in the body furnished more material for the formation of fat, and the carbhydrates were sufficient to protect a large part of it from oxidation. These and similar researches obviously speak strongly in favor of the theory that fat is formed from the albuminoids and not from the carbhydrates.

Naturally, a certain relation must subsist between the latter and the amount of fat formed. Since the carbhydrates protect the fat from oxidation, a greater quantity of them must protect more fat up to a certain limit; but if more carbhydrates are given than are necessary to protect the fat, the excess seems not to produce fat but to be oxidized.

The relative Effect of Fat and Carbhydrates in effecting a gain of fat or protecting the body fat from oxidation, is not in proportion to their respiration equivalents.

By the respiration equivalent, as explained on p. 157, we understand the relative quantities of heat which equal weights of the given substances will produce when completely burned.

It may be expressed in another way by saying that they represent the relative amounts of oxygen with which equal weights of the given substances combine when completely oxidized. Thus, if a certain weight of starch, *e. g.*, requires for its complete combustion one gramme of oxygen, the same weight of fat will require 2.5 grammes of oxygen; and if we represent the respiration equivalent of starch by 1, that of fat is 2.5, while that of the other carbhydrates is practically equal to that of starch, viz., 1.

Since, now, the chief office of the carbhydrates seems to be to protect other substances from oxidation by themselves combining with the oxygen, we might naturally expect that one part of fat would be equivalent in this respect to 2.5 parts of a carbhydrate; and before any exact observations had been made, this was assumed to be the case. The few experiments as yet made, however, have shown that this assumption is erroneous, and that one part of fat is equivalent not to 2.5 parts of a carbhydrate, but to only about 1.75 parts, while, as we have seen (p. 157), their action in decreasing the protein consumption is about the same, weight for weight. In the animal body we have to do, not with a machine into which fuel is put to be burned, but with a living organism. The materials of the body and the food are decomposed in the performance of the vital processes, while the burning of them by the oxygen of the blood is only a secondary process, and any conclusions drawn from the chemical composition of nutrients and their behavior outside the body, are of very uncertain application to the complicated processes which take place within it.

The importance of these facts for the practice of feeding is obvious. The carbhydrates are the cheapest of the nutrients, and the most easily digestible, while fat is expensive and difficult of digestion by herbivorous animals. When we add to the two facts just mentioned—viz., the equivalence of fat and carbhydrates in their effect on flesh production, and the value of the latter as an aid to fat production—the possibility of a direct formation of fat from carbhydrates, the great importance of this class of nutrients becomes evident.

Fattening.—In fattening animals for market, the chief endeavor is to produce fat, and only in a subordinate degree to cause a formation of flesh. Indeed, after an animal has completed its growth but little more formation of actual flesh (organized protein) takes place, although the quantity of circulatory protein, and so the juiciness of the meat, may be increased.

In all cases, a certain minimum amount of protein and non-nitrogenous nutrients is necessary to maintain an animal *in statu quo*; but this amount varies according to the condition of the body. If the latter is rich in circulatory protein on account of previous rich feeding, the food must contain much protein; if it contains little circulatory protein, a small amount of albuminoids in the fodder will suffice. If the body is fat, a smaller ration of albuminoids is necessary to maintain its condition than when it is lean.

If we increase the fodder beyond the amount necessary for maintenance, a production of some sort results.

If the amount of the non-nitrogenous nutrients be increased, we shall get (up to a certain limit at least) a production of fat; if the protein be increased, we shall have an increased protein consumption in the body, but also a gain both of flesh and fat.

The proper proportions of nitrogenous and non-nitrogenous nutrients in a fodder, then, obviously depend on the object of the feeding. If we desire to render the body rich in protein, to cause a good development of its organs, and render it capable of great exertions, we shall feed plenty of albuminoids together with enough non-nitrogenous nutrients to protect the fat of the body from oxidation and to diminish the protein consumption as much as possible while not causing any considerable fattening, and we shall give the animal as much of this fodder as possible, because the greater the amount of food of a given composition eaten, the greater, other things being equal, is both the absolute and the relative production. (See p. 167.)

On the other hand, if we wish to fatten the animal, we shall proceed differently. With any given number of pounds of protein in the daily fodder, the greater the amount of non-nitrogenous nutrients taken into the system the more fat is protected from oxidation and the less becomes the protein consumption. In other words, having once fixed on the number of pounds of protein to be given per day and head, the more carbhydrates and fat we can introduce into the system along with it the greater will be the production both of flesh and fat.

We shall consequently incline to make the nutritive ratio of our fattening fodder wider than that for working animals; but in doing this we shall not forget that a certain absolute amount of protein is necessary.

Leaving out of account the possible formation of fat from carbhydrates, there is no doubt that a certain proportion of protein in the fodder is essential to rapid and profitable fattening, especially of ruminants, while it is, of course, the only source of material for the formation of flesh. Since, now, an animal can consume only a certain total amount of food, our first care will be to see that that food contains enough protein; while, in the second place, we shall introduce into it enough carbhydrates and fat to insure a production of fat and prevent any unnecessary protein consumption.

Thus it will be seen that a consideration of the general principles brought out in the last two chapters leads to important practical conclusions. The application of these general principles to the feeding of domestic animals, the determination of the quantity and proportions of the various nutrients which are necessary to attain most speedily and profitably the various ends of feeding, forms the object of the science of cattle-feeding, and it is the clear recognition of this fact and the intelligent pursuit of this object which has caused the rapid advances of the past few years.

What has already been achieved in this respect will form the subject-matter of Part III.

§ 6. INFLUENCE OF OTHER CONDITIONS ON THE PRODUCTION OF FAT.

Influence of the Fat of the Body.—In a body rich in fat the total fat-consumption, and also the proportion of the fat of the food which is oxidized, is greater than when the body contains little fat; in the latter case, the fat from the food, or from the oxidation of the albuminoids, is more readily stored up, while in the former case greater obstacles seem to stand in the way of a further accumulation of fat.

Excessive Drinking.—According to our present knowledge, excessive drinking of water increases the consumption of fat in the body, just as it does that of the protein. (See p. 135.) Too watery fodder and too much drinking are therefore to be avoided, especially in fattening, if we wish to attain the most rapid and abundant formation of flesh and fat.

Too low or too high a Temperature of the stall seems also to act unfavorably on fattening: the first, because an increased oxidation of food constituents is necessary to maintain the vital heat; the second, because it causes perspiration, which exerts two evil effects: first, by causing increased drinking, and second, by absorbing heat from the body by its evaporation, just as water sprinkled on the floor on a hot day absorbs heat as it evaporates, and so cools the room. Every such loss of heat is equivalent to a loss of substance, since the heat is produced by the oxidation of the materials of the body or of the food. Too high a temperature is also liable to make the animals restless and diminish their appetite. A medium temperature of from 55° to 70° F. is the most favorable for fattening.

Muscular Exertion, as we shall see more in detail in the next chapter, increases the consumption of fat very considerably. Too much movement by fattening or milking animals is therefore to be avoided. This is true not only of outward motions but of the internal motions of the body in digestion, etc. If a very bulky fodder be given, the increased work of moving it in and through the digestive apparatus cannot but have its influence in increasing the oxidation and destruction of fat. Doubtless one of the advantages of concentrated and easily-digestible fodders is the saving in internal work which they effect.

The Amount of Oxygen taken up by the Blood is a not unimportant factor in the production of fat. The decompositions which take place in the body are, as we have already seen, vital processes, and the taking up of oxygen is a consequence and not a cause of them.

At the same time, the maximum amount of oxygen that can be introduced into the system is determined by the amount of blood and its content of hæmoglobin, this substance being the active agent in taking up the gas, and this, of course, sets a limit to the amount of matter that can be oxidized in the system. Consequently a small amount of blood and a small proportion of hæmoglobin are conditions favorable for the production of fat.

According to the observations of Subbotin,* the chief factor in determining the amount of hæmoglobin in the blood seems to be the nature of the food. The blood of a dog, *e. g.*, fed on a richly nitrogenous diet, was found to have 13.73 per cent. of hæmoglobin, while on a non-nitrogenous diet it sank to 9.52 per cent. He also found that the blood of herbivorous animals, which generally receive a fodder comparatively poor in nitrogen, contained less hæmoglobin than that of carnivorous animals, which receive a more nitrogenous food.

We shall see in Chapter VIII. that an increase of the albuminoids of the food increases the capacity of the body to store up oxygen, and here we get a hint as to the way in which this effect may be produced.

One other factor determining the amount of hæmoglobin seems to be the amount of fat already contained in the body. Subbotin found considerably less in the blood of lean than of fat animals.

That a decrease of the hæmoglobin aids the production of fat is indicated by various facts.

In some parts of Germany bleeding is resorted to, to increase the rapidity of fattening, and it has been found by respiration experiments that this operation, while it increases the protein consumption, decreases that of fat, apparently by removing part of the blood corpuscles (hæmoglobin), the agents by which oxygen is introduced into the system. It is also a fact of experience that the body, when deficient in blood, is often inclined to lay on fat. It is well known, too, that herbivorous animals are, in general, easier to fatten than carnivorous, and it is more than probable that this is due, in part at least, to the smaller amount of hæmoglobin contained in their blood, while the differences observed between different breeds in this respect may be partly owing to the same cause.

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* Zeitschr. f. Biologie, VII., 185.

In cases of phosphorus-poisoning, an enormous formation of fat is observed, amounting sometimes to fatty degeneration of the tissues. Phosphorus acts as a poison by depriving the blood of oxygen, and as one of the effects of this we see an abnormal formation of fat, due apparently to the poverty of the blood as regards oxygen.

The amount of oxygen taken up by the blood must also be influenced by the amount of lung surface, the rapidity of circulation and respiration, etc.; but while it is a popular and perhaps well-founded belief that the differences observed between different animals as regards ease of fattening, are largely due to differences in build, especially in the size of the lungs, there has been as yet no scientific study of this interesting question.

CHAPTER VIII.

THE PRODUCTION OF WORK.

In its most general sense, the production of work means the conversion of latent into actual energy. In the animal, it is the latent energy contained in the various components of the food or the body, which is thus converted, during the resolution of these components into simpler substances. Every ingredient of the food contains a certain fixed amount of force; every one of the simpler compounds into which it may split up in the body also contains its smaller but equally definite amount of force, and the difference between the latter and the amount contained in the original substance expresses exactly the amount of force which that substance is capable of contributing to the body.

The production of force in the body has been compared to the operations of a steam-engine.

In the engine, the force exerted is set free as heat from the coal burned under the boiler, and is then converted, by appropriate mechanical arrangements, into motion of the engine; in the body the force set free by the combustion of the materials of the food appears partly as heat and partly in other forms. Just as the burning of fuel under a steam-boiler may do various kinds of work, such as heating, producing chemical change, or causing motion of the engine, which motion, again, may be applied to various purposes, such as pumping water for the boiler, drawing coal for the fire, driving the machinery of a shop, etc., so the energy set free in the body takes various forms. It may appear as heat, or as motion, it may take the form of electrical currents, or it may produce chemical changes, such as the formation of a complex compound out of simple ones. All these phenomena we class together under the general name of the production of work.

It is obvious at once that the production of work is antagonistic to the formation of the material products for which animals are frequently kept. All work is performed at the expense of food or tissue, and the more work is performed the less material remains for the production of flesh, fat, milk, etc.

This is a common observation as regards external work —no one would undertake to fatten a laboring animal— but it is equally true of such less obvious forms of work as the production of heat or of chemical change. Plainly, then, we have a very practical interest in knowing what constituents of the food or of the body are destroyed in the performance of the various kinds of work, since all the material losses thus occasioned must finally be supplied by the food.

One kind of work, viz., muscular exertion, has been the subject of much study and controversy; and though we do not even yet know with certainty what substance or substances are the source of muscular power, yet what has been learned is of great value. Other forms of work, on the contrary, have received comparatively little attention, and offer a wide field for investigation.

In the following pages we shall take up first the production of external work and its bearings on the feeding of working animals, and then attend to a few considerations concerning the internal work of the body.

§ 1. Effects of Muscular Exertion on Excretion.

Voit's Experiments.—It was formerly the common belief that continued activity of the muscles caused a wearing out of those organs, and, as a consequence, largely increased the protein consumption and the excretion of nitrogen. This belief, however, was never founded on experimental evidence, and has now been rendered untenable in its original form.

Karl Voit, of Munich, was the first to make exact experiments on the subject, and in 1860 he published the results of his researches,* which showed that, contrary to the then generally accepted theory, muscular exertion did not increase the amount of protein decomposed in the body.

His experiments were made on a dog weighing about 32 kilogrammes (70 lbs.). The work which he performed on the working-days (by running in a treadmill) was very considerable, being estimated at 1.7 kilogramme-metres † per second for the whole twenty-four hours (the work being actually performed in six periods of ten minutes each), while the work performed by a man working eight hours in the twenty-four is estimated at only 2.3 kilogramme-metres per second for the twenty-four hours. In some of the experiments the animal received no food; in others he was given a daily ration of 1,500 grammes of fat-free meat, with which amount the body was allowed to come into equilibrium before the beginning of the experiment. The diet on the resting and working-days was always the same, except that the animal was allowed to drink all the water he desired. Each experiment extended over three days. The following results are averages for twenty-four hours:

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* "Untersuchungen über den Einfluss des Kochsalzes, des Kaffee's und der Muskelbewegungen auf den Stoffwechsel," 1860.

† A kilogramme-metre is the amount of force required to raise one kilogramme through a space of one metre, in opposition to gravity.

Number of Experiment.	Meat eaten. Grms.		Water drunk. Grms.	Urine excreted. Grms.	Urea excreted. Grms.
I.	0	Rest.	258	186	14.3
		Work.	872	518	16.6
II.	0	Rest.	123	145	11.9
		Work.	527	186	12.3
		Rest.	125	143	10.9
III.	1,500	Rest.	182	1,060	109.8
		Work.	657	1,330	117.2
		Rest.	140	1,081	109.9
IV.	1,500	Work.	412	1,164	114.1
		Rest.	63	1,040	110.6

The 1,500 grammes of meat eaten in Experiments III. and IV. contained 1,138 grammes of water, which is to be added to the amount drunk.

These results show, at most, only a very slight increase of the protein consumption on the working days. On the days of fasting the increase, as measured by the excretion of urea, was 11.5 per cent., and with the meat ration only 4.8 per cent.; and even this small increase appears to be due, not to the work but to the greater amount of water drunk and excreted in the urine, since, as we have already learned (p. 135), an increased excretion of water in the urine causes an increase in the protein consumption. Voit found that an increase of 100 grammes of water in the urine caused, in the dog, a plus of 1.7 grammes of urea. If this relation is applicable to the above experiments, it practically covers the comparatively slight increase of urea observed on the working days, and we must consequently assume that muscular exertion does not essentially increase the protein consumption in the body.

Experiments by Pettenkofer & Voit.—The correctness of this conclusion is shown by some subsequent experiments by Pettenkofer & Voit* on a man, in which the amount of water drunk was regulated, and the above-mentioned source of uncertainty thus avoided. In these experiments the respiratory products were also determined, and the influence of work upon the non-nitrogenous constituents of the body thus ascertained.

On the work-days the subject of the experiments turned for nine hours, with occasional pauses, a heavy wheel provided with a brake, and at night felt fatigued as after a hard day's work or a long march. With the aid of the respiration apparatus the following numbers, which all refer to a space of twenty-four hours and are mostly the average of two or three concordant experiments, were obtained:

	Nitrogen of urine. Grms.	Carbonic acid excreted. Grms.	WATER EXCRETED.		Oxygen taken up. Grms.	Number of experiments.
			In urine. Grms.	Evaporated. Grms.		
FASTING.						
Rest	12.4	716	1,006	821	762	2
Work........	12.3	1,187	746	1,777	1,072	1
AVERAGE DIET.						
Rest	17.0	928	1,218	931	832	3
Work	17.3	1,209	1,155	1,727	981	2

These figures prove most decidedly that the protein consumption is no greater during work than during rest, but that, on the other hand, the consumption of fat, and as a result the excretion of carbonic acid and taking up of oxygen, is greatly increased, as is also the amount of water evaporated through lungs and skin. In hunger the difference between the carbonic acid in rest and in work is more considerable (471 grammes) than on an average diet (281 grammes); the oxygen shows a similar result, 310 grammes against 148 grammes, while the differences in the water evaporated are relatively less, viz., 956 and 796 grammes.

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* Zeitschrift f. Biologie, II., 478–500.

One might perhaps be inclined to believe that while the total amount of albuminoids consumed in the twenty-four hours was the same, the amount was larger during the period of work, and correspondingly less during the hours of rest. In order to test this, the experiments were each divided into two parts, the time from 6 A.M. to 6 P.M., in the course of which the work was performed, being designated as day, and the time from 6 P.M. to 6 A.M. as night. The following results were obtained for the nitrogen, carbonic acid, and water excreted:

	Fasting.				Average Diet.			
	Rest.		Work.		Rest.		Work.	
	Day. Grms.	Night. Grms.	Day. Grms.	Night. Grms.	Day. Grms.	Night. Grms.	Day. Grms.	Night. Grms.
Urinary nitrogen *.......	7.07	5.32	5.91	6.35	8.88	7.99	8.95	8.12
Carbonic acid..	403.00	313.00	930.00	257.00	533.00	395.00	856.00	353.00
Water evaporated.......	454.00	367.00	1,425.00	352.00	441.00	490.00	1,065.00	662.00

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* The slight differences between these figures and those of the table on p. 206 are due to discrepancies in the original account of the experiments.

These results show, first, that the decompositions, both of protein and of non-nitrogenous matters, going on in the body are more active during the waking hours than at night, a fact which has been abundantly confirmed by other observations; and second, that the performance of muscular work during the day has practically no effect on the extent of the protein consumption, while it largely increases the amount of carbonic acid and water exhaled during the day.

That muscular exertion causes an increased excretion of carbonic acid and water is universally acknowledged; but, in spite of the decisive results of Pettenkofer & Voit, and the corroborative results of various other investigators, the fact of the constancy of the nitrogen excretion under the influence of work has been disputed.

Excretion of Gaseous Nitrogen.—That under ordinary circumstances no excretion of free nitrogen from the body takes place has been already shown; but it has been sometimes claimed that in severe work a portion of the nitrogen coming from the destruction of the albuminoids is excreted in the gaseous form through skin and lungs, and that consequently the protein consumption cannot be calculated from the urinary nitrogen. According to this, the close agreement observed in the above and many other experiments between the urinary nitrogen on the days of rest and work is entirely accidental—a thing which is certainly very improbable of itself, and which is disproved by the following considerations and experimental results.

If, in consequence of work, the total protein consumption is considerably increased, there must be a correspondingly increased excretion of sulphuric and phosphoric acids in the urine; for with every portion of albuminoid tissue destroyed, the sulphur and phosphorus which it contains must be oxidized to sulphuric and phosphoric acids and finally leave the body in the urine, since these acids cannot assume the gaseous form at the temperature of the body. In the above experiments the quantity of these acids was determined in the experiments made on an average diet, and the following results obtained:

	Sulphuric acid. Grms.	Phosphoric acid. Grms.
Rest	2.61	4.19
Work	2.57	4.11

The quantities in rest and work are identical within the limits of error.

Kellner's Experiments.—Almost all investigators who have experimented upon this subject have obtained results agreeing in the main with those of Pettenkofer & Voit, while most of those who have reached contrary conclusions have used palpably imperfect methods of experiment.

Some late researches by Kellner * seem to indicate, however, that Pettenkofer & Voit's experiments may not cover the whole ground. In none of the experiments hitherto described was the work continued for any considerable length of time. In Voit's experiments it was confined to periods of ten minutes each, and in those of Pettenkofer & Voit it was continued only for a few days at most, and under these circumstances caused no increase in the protein consumption.

Kellner's experiments were made at the Hohenheim Experiment Station, on a horse. They included five periods of from one to two weeks each, during each of which the work performed per day was the same, while the amount of fodder and its digestibility did not vary essentially during the whole series of experiments. The work performed was measured by a dynamometer constructed for the purpose, and was as follows:

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* Landw. Jahrbücher, VIII., 701.

Period I	475,000 kilogramme-metres.*
" II	950,000 "
" III	1,425,000 "
" IV	950,000 "
" V	475,000 "

The digestibility of the food was determined directly. The following averages were obtained for the daily excretion of nitrogen and the total volume of the urine during the first and second halves and the whole of each period:

Period.	NITROGEN IN URINE.			Nitrogen of food.† Grms.	VOLUME OF URINE.		
	1st half. Grms.	2d half. Grms.	Whole. Grms.		1st half. c.c.	2d half. c.c.	Whole. c.c.
I	....	....	99.0	134.41	....	....	6,730
II	107.6	111.0	109.3	128.32	6,482	6,464	6,473
III	113.2	120.5	116.8	132.72	7,773	8,439	8,106
IV	112.6	107.7	110.2	126.40	9,247	8,129	8,686
V	94.7	101.9	98.3	129.41	9,647	9,447	9,548

These results show that "an increase of the protein consumption went hand in hand with the increase of the work;" but whether the former was a direct result of the latter can be decided only after a careful consideration of all the factors which may have exerted an influence upon the protein consumption.

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* A kilogramme-metre is the amount of force required to raise a weight of one kilogramme through the space of one metre, in opposition to gravity.

† Landw. Jahrbücher, VIII., I. Supp., p. 77.

Attention has already been called to the fact that an increased excretion of water in the urine is accompanied by an increased excretion of nitrogen also. A glance at the table shows, however, that in these experiments the volume of the urine increased constantly from one period to another, and therefore cannot well have been the cause both of an increase and decrease of the ureal nitrogen.

A second point to be considered is the effect of prolonged work in altering the make-up of the body, especially as regards the proportion of fat. It has already been pointed out that muscular exertion causes an increased destruction of the fat of the body, and that this was the case in these experiments is shown by the gradual decrease of the weight of the animal during the first four periods, as follows:

Average weight in Period	I.	1,175 lbs.
“ “ “	II.	1,165 “
“ “ “	III.	1,150 “
“ “ “	IV.	1,119 “
“ “ “	V.	1,140 “

Since, as shown by the table, the nitrogen excretion was less than the supply, this loss of weight must have been caused chiefly by a destruction of fat consequent upon the increased work.

But, as shown in Chapter VI., the body-fat tends to diminish the protein consumption, and, on the other hand, a loss of fat by the body would have the opposite tendency; and we have therefore to consider whether the variations in the protein consumption here observed can be explained in this way. Obviously the increase in the first three periods might have been due to this cause, but it was observed that in passing from Period III. to Period IV., and from this to Period V., the amount of ureal nitrogen sank *at once* to about the average for the respective periods.

Thus, in the last four days of Period III. the average daily excretion of nitrogen was 124.4 grammes, and in the first four days of Period IV., 104.8 grammes.

It is easily conceivable that, on passing from a period of more to one of less work, fat should be again laid up in the body and the protein consumption thus diminished, but it is evident that such an effect would be gradual, and we cannot imagine that it should cause any such sudden change as that just mentioned.

We are consequently shut up to the conclusion that, under the conditions of these experiments, the protein consumption was greater or less according as more or less work was performed, and it would thus appear that while a moderate amount of work, like that performed in Voit's experiments, does not sensibly increase the protein consumption in the body, long-continued exertion may, on the contrary, have that effect.

It is of interest to note, in this connection, some experiments made in 1867 by T. R. Noyes,* then a student in the Yale Medical School.

His experiments were, in the main, confirmatory of Voit's results, but in the case of one of the subjects, in whom the muscular exertion produced great fatigue and exhaustion, an increased excretion of urinary nitrogen was observed as a result of work, and the author suggests as possible that, while ordinary work does not increase the destruction of protein, exertion sufficient to produce exhaustion may do so. This conclusion appears to be in harmony with Kellner's results.

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* Am. Jour. Med. Sci., Oct., 1867.

§ 2. THE SOURCE OF MUSCULAR POWER.

Thus far we have simply been considering experimental results, without regard to the conclusions to be drawn from them. We now come to their interpretation, and here it must be admitted, at the outset, that the knowledge as yet gained is insufficient to enable us to state with certainty the source of muscular power.

Any elaborate discussion of the question would be out of place here, and we shall simply endeavor to present some general considerations bearing on this point, and to indicate what seem, in the present state of our knowledge, to be the most probable conclusions.

Increased Oxidation of Source of Power not necessary.—At first thought the results detailed in the preceding section seem to plainly indicate the non-nitrogenous ingredients of the body as the source of muscular power, since these undergo an increased oxidation during work, while the protein does so at most only to a small extent, if at all; and in fact many eminent physiologists hold that it is the decomposition of these bodies which supplies the energy for the production of work.

But this is by no means a *necessary* conclusion. We must distinguish between the source and the consequence of muscular exertion. The continual decomposition of matter which goes on in the living body must be accompanied by the liberation of a corresponding amount of force. Part of this force is set free as heat, part probably as electricity, continual currents of which circulate in the living muscle. Now it is quite conceivable that, in muscular exertion, part of this force is diverted from these channels, and takes the form of muscular contraction, while the *increase* in the oxidation of non-nitrogenous matter is a consequence, and not a cause, of the work.

Voit, who believes the albuminoids to be the proximate source of muscular power, advances this argument, and compares the constant decomposition of protein which goes on in the body to the constant flow of water in a stream. A mill situated by the stream may use the whole power of the water, a half, a quarter, or any desired fraction, without in the least altering the amount of water running past. So, according to him, the decomposition of protein in the body, which is the source of power to the muscles, goes on constantly, independently of whether the energy which is set free takes the form of motion or appears in some other shape.

Pettenkofer & Voit (see Chapter VII.) have shown it to be at least very probable that protein in its decomposition in the body takes up the elements of water and splits up into urea and *fat;* and it has been shown that 100 parts of protein might produce in this way 51.4 parts of fat. This process, now, takes place during rest, and the supposition is quite plausible that during work the protein is decomposed completely into carbonic acid, water, and urea, and that thus the latent energy which would otherwise be stored up in the fat is applied to the production of motion.

It is plain, however, that this argument may be used with equal force to show that the non-nitrogenous matters of the body may be the source of muscular power.

In truth these considerations simply serve to show that a study of the *effects* of work cannot give us decisive information as to its *source*, both because the production of muscular exertion does not necessarily imply an increased decomposition of the source of the power and because secondary effects may come in to vitiate our conclusions. We must, then, seek for further evidence.

Force Value of Nutrients.—Much valuable evidence concerning the question under discussion may be gained by a consideration of the force value of food, and the advocates of the non-nitrogenous matter as the source of muscular power rely largely, in support of their views, upon calculations of this sort, *i. e.*, calculations of the amount of force that can be liberated by the conversion of a certain amount of albuminoids, fat or carbhydrates into the final products of their oxidation in the body, viz., carbonic acid, water and urea.

The basis of this calculation is the amount of *heat* which the several nutrients evolve when burned. For example: one gramme of albumin, when completely burned, evolves a certain definite amount of heat; the urea from one gramme of albumin likewise evolves a definite, though smaller, amount when burned. Subtracting the latter from the former, we have left the amount of heat which would be produced by the conversion of one gramme of albumin into carbonic acid, water, and urea, and this amount, by a well-known law of physics, is equivalent to a certain fixed amount of mechanical motion — that is, work.

Having once obtained, then, accurate data as to the heat of combustion of each substance involved, and knowing the amount of work performed, we are able to estimate whether, in a given case, the amount of any substance or class of substances destroyed during the experiment is sufficient to set free the amount of force actually exerted.

The earliest and best known experiment of this sort is that made by Fick & Wislicenus,* in 1866. These observers found that in the ascent of an Alpine peak (the Faulhorn) the amount of protein decomposed, as measured by the urea excreted, was not sufficient, according to their calculations, to yield the amount of force actually exerted in raising their bodies to the height of the mountain, although no allowance was made for the work of the internal organs or for those muscular exertions which did not contribute to the raising of their bodies, and though the heat of combustion of protein was, in the absence of positive data, assumed to be considerably higher than it was afterward found to be by Frankland.

Here we have a perfectly definite amount of work performed and the most favorable assumptions made on doubtful points, and yet we have a considerable deficit of force, if the albuminoids alone are taken into account.

At the time when Fick & Wislicenus made their experiment no data as to the heat of combustion of the nutrients were available; but shortly afterward Frankland † took up the matter and made a large number of experiments with the object of accurately determining these important quantities. His results have served as the basis for several calculations similar to those of Fick & Wislicenus, most, if not all, of which have led to the same conclusion as did theirs, viz., that the observed decomposition of protein was insufficient to account for the amount of force actually exerted.

These results, if trustworthy, show that at least a portion of the force exerted in muscular work must be contributed by other ingredients of the food than protein.

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* Phil. Mag., XXXI., 485.

† Ibid., XXXII., 182.

No calculations seem to have been made regarding the relations of fat-consumption and work in this respect.

Unfortunately, considerable uncertainty attaches to the very foundation on which all of these results rest, viz., the heat of combustion of protein. According to Voit, there is good reason to believe that in Frankland's experiments the nitrogenous substances, especially, were incompletely burned, and that consequently his results on these bodies were too low, and Zuntz * has shown it to be at least probable that the heat of combustion of protein as determined by Frankland should be increased more than 25 per cent., and that even then it may be considerably too low. But Frankland's determinations are the only ones of this kind that we yet possess, and it is therefore evident that, until these are either proved to be accurate or replaced by others, no certain conclusions can be drawn from computations of the force-value of food as to the production of muscular power, although such results as have been obtained on the present uncertain basis indicate strongly that the non-nitrogenous constituents of the food or body take part in the process.

It may be added here that the *increase* in the protein-consumption observed in Kellner's experiments was not sufficient to supply the extra force exerted in the second and third periods, even if the heat of combustion of protein as corrected by Zuntz be used as the basis of the calculation.

Conditions of Muscular Exertion.—If we turn from the study of the effects of muscular exertion to that of its conditions, we shall get much new light, and be helped to a more rational judgment of the theories as to its source.

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* Landw. Jahrbücher, VIII., 72.

Presupposing the existence of a healthy and well-developed organism, we may specify *four* conditions as, from our point of view, the most important:

1. The facts of common experience appear to show unmistakably that a liberal supply of protein in the food is one of the conditions of any sustained muscular exertion. Working animals must receive not only an abundance of food, but of food rich in protein, and the more severe the work, the more concentrated must be the food; and the same fact is equally true of the human animal. This, however, does not necessitate the conclusion that the protein is the source of the power exerted: its decomposition, as we have seen, goes on independently of muscular exertion, and may be regarded as simply one of the conditions of the healthy activity of the muscles or of their normal nutrition.

2. The largely increased excretion of carbonic acid and water during work indicates a necessity for a liberal supply also of the non-nitrogenous constituents of food. At need, however, this demand may be supplied by the albuminoids or perhaps by fat already formed in the body.

3. An essential condition of continued activity of the muscles is the constant removal from them by the circulation of the carbonic acid and other chemical products formed during contraction. Certain of these products, notably lactic acid and acid potassium phosphate, if allowed to accumulate in the muscle, produce the sensation of weariness and shortly incapacitate it for further action. If they be removed, either by the blood or by injection of a weak salt solution, the muscle is again capable of work; while, if they be injected into a fresh muscle, they produce the same effect as if naturally formed there. The same accumulation of waste products goes on in the muscle after

death, and the *rigor mortis* is caused by the solidification of the jelly-like *myosin*, which is also one of the substances formed in muscular action.

4. A most important condition of continued muscular activity is found in the capacity which the body has of storing up within itself, during rest, a reserve of force, to be used later as demands are made upon it.

After working for a certain time we experience a feeling of fatigue, or, if the exertion be continued long enough, of exhaustion, and require a period of rest before the muscles are capable of again performing work. The same thing is true of the involuntary muscles. Even those which, like the heart and the respiratory muscles, seem to work continually, really have relatively long intervals of rest between each exertion. Thus, the heart is calculated to be at rest for about one-third of the time. Work is only possible when alternated with periods of rest; and while the nervous system has undoubtedly much to do with the need for rest, there is no doubt that it is also required by the muscles, to enable them to repair the waste occasioned by work.

This well-known fact is sufficient to show that the force of muscular exertion is not produced by a direct combustion of muscle substance by means of the oxygen of the blood, as coal is burned under a boiler, since, if this were the case, there would be no reason why it should not go on indefinitely. It is the sudden utilization of latent energy which has been laid up during rest.

That the seat of this latent energy is in the muscles themselves is shown by the fact that they are capable of contraction for a time after their blood-supply has been cut off, or even after their removal from the body. A frog's heart, when removed from the body and freed from all blood by injection of a weak solution of salt, will continue to beat for hours, and the whole animal, under the same circumstances, moves, leaps, and behaves in short like a living animal. Agassiz relates that on one occasion he captured a shark, which fought as long and fiercely as is usual with these animals, but which, when finally secured, was found to have its gills eaten through by parasites, and almost all its blood replaced by sea-water. (Liebig.)

In cases like these, the products of the muscular action being continually removed by the salt solution, etc., the muscles may continue active until their store of force is exhausted. Like a bent spring, the muscle contains a certain amount of potential energy, which the will can use at pleasure; but when the supply is once exhausted, when the spring has lost its tension, a further supply of force from without is necessary before more work can be performed.

We have to consider, then, in what manner and by means of what substances this storing up of energy takes place.

Storing up of Oxygen.—It would appear that the storing up of oxygen in the body which has been shown by Pettenkofer & Voit and by Henneberg (see pp. 85-87) to take place under certain circumstances, is connected with the storing up of energy.

In the following tables are given the amounts of carbonic acid excreted and of oxygen taken up in two of Pettenkofer & Voit's experiments which strikingly illustrate this point. The numbers in the column headed "R" are relative, and show how many grammes of oxygen appeared in the excreted carbonic acid for every hundred grammes taken up from the atmosphere.

These experiments are included in the averages on p. 207.

AVERAGE DIET—REST.

	Carbonic acid excreted. Grms.	Oxygen taken up. Grms.	R.
6 A.M. to 6 P.M.	533	235	175
6 P.M. to 6 A.M.	379	474	58
6 A.M. to 6 A.M.	912	709	94

AVERAGE DIET—WORK.

6 A.M. to 6 P.M.	884.6	293.8	218
6 P.M. to 6 A.M.	399.6	660.1	44
6 A.M. to 6 A.M.	1,284.2	953.9	98

It will be observed that while in each case more carbonic acid was excreted by day than by night, the larger amount of oxygen was taken up during the night. Moreover, the numbers in the last column show that at least a very considerable part of the carbonic acid excreted during the day must have been formed at the cost of oxygen already present in the body, since that taken up from the air during the same time was far less than the amount contained in the excreted carbonic acid.

A comparison of the two experiments also shows that of the increase of the carbonic acid excretion caused by work (372.2 grammes), by far the larger part (351.6 grammes) occurred during the hours when the work was performed, while the oxygen taken up during the same time increased only 58.8 grammes, against 186.1 grammes in the following night.

Further experiments by the same investigators, while not always yielding as striking results as did these two, confirmed in the main the conclusions drawn from them. It was found, it is true, that the storing up of oxygen did not always take place by night, as in these experiments; but the fact that oxygen may be retained in the body in considerable quantities was fully established.

One other important point was observed in Henneberg's earlier experiments on this subject, viz., that the greatest storing up of oxygen took place in those experiments in which the fodder was richest in albuminoids.

These experiments extended over only twelve hours, corresponding to the "day" half of Pettenkofer & Voit's experiments, and in almost every case it was found that the carbonic acid excreted contained more oxygen than was taken up by the body during the same time, thus showing a formation of carbonic acid at the expense of oxygen previously stored up. The following summary of the results shows that this excess of oxygen was, in general, greatest in those cases where most albuminoids were fed:

Number of Experiment.	Protein of fodder. Lbs.	Oxygen taken up. Lbs.	Oxygen in carbonic acid. Lbs.	Ratio of the two.
1.......	0.79	4.25	5.42	1 : 1.28
2.......	0.82	2.63	4.34	1 : 1.65
3.......	0.80	3.20	4.65	1 : 1.45
5.......	0.89	3.83	6.01	1 : 1.57
6.......	0.78	5.20	6.67	1 : 1.28
7.......	2.60	3.00	7.13	1 : 2.38
8......	2.51	3.40	7.63	1 : 2.24

This alternate storing up and giving off of oxygen by the body has also been observed in physiological experiments of an entirely different character, which can only be alluded to here.

That the storing up of energy is connected with the storing up of oxygen is indicated by a few experiments by Pettenkofer & Voit on two diseases in which the patient is almost incapable of muscular exertion, viz., diabetes and leukæmia. In these experiments the total excretion and the total amount of food were not much different from those in health; but there was no such storing up of oxygen as in the healthy organism, and there was also, as is usual in these diseases, an almost entire lack of strength.

But Pettenkofer & Voit's and Henneberg's results are especially valuable for our present purpose because they show that muscular power does not have its origin in a simple oxidation but in the "explosive" decomposition, independently of oxygen, of material already prepared in the muscle, a conclusion to which we are also led by the fact, already noted, that the muscle is able to perform work for a considerable time independently of oxygen, provided the resulting decomposition products are removed.

Conclusions.—We have learned in the foregoing pages that, presupposing the existence of a healthy and well-nourished organism, muscular exertion is possible when the chemical products of the action are removed from the muscles, and when the body has had the ability and opportunity to lay up a store of latent energy; that this storing up of energy is effected by the entrance of oxygen from the air into combination with the organic substances of the muscles; that when work is performed this oxygen reappears in combination with carbon and hydrogen as carbonic acid, water, and other products; that this process results in an increased excretion of carbonic acid and water, while the excretion of nitrogen remains, in most cases at least, unaltered; and finally, that the amount of work performed is in many cases greater than can be accounted for by the amount of protein which the urinary nitrogen shows to have been decomposed.

All these facts are well ascertained, and they enable us to frame an hypothesis which, though confessedly but a rough and approximate one, is still considered by many high authorities to accord more closely with the facts of the case and with our general conceptions of vital activity than those which place the source of muscular power in protein on the one hand, or non-nitrogenous matters on the other.

This hypothesis supposes that during rest some of the substances of the muscle-cells decompose into simpler compounds, and in so doing set free their latent energy, and that this energy, instead of appearing as heat, etc., is used to build up out of other constituents of the cell a still more complex compound, containing more potential energy than its components, just as one portion of society may acquire wealth at the expense of another portion without increasing the total wealth of the community.

The substances which are thus "synthesized" are protein, non-nitrogenous matter from the blood, and oxygen. The hypothetical compound thus formed, after accumulating to a certain extent, decomposes during rest as rapidly as it is formed. When the muscle is called on to perform work, however, it splits up rapidly, yielding carbonic acid, water, and other non-nitrogenous matters, and a nitrogenous compound, and giving forth the amount of force which was required to form it. The non-nitrogenous substances which are formed are supposed to be rapidly excreted, while the nitrogenous product, instead of undergoing further decomposition, is used over again to re-form the hypothetical substance.

This view has much in its favor. Various syntheses, more or less like that above outlined, are known to take place in the body; and, moreover, we have seen that all the facts seem to indicate that muscular force originates in a splitting up of some substance in the muscle, rather than in any process of oxidation in the ordinary sense of the word.

The hypothesis explains the object of the storing up of oxygen in the body during rest, and its connection with the laying up of a reserve of force: the oxygen enters into the supposed complex compound much as the nitric-acid radicle enters into nitro-glycerine or gun-cotton—it is held in a state of unstable equilibrium, ready to enter into new and simpler relations with its neighboring atoms and to set free the force by which it was placed in its unstable position. The hypothesis also brings that necessity for albuminoids in the food of the laboring animal which practical experiènce has shown to exist, into harmony with the fact that there is no greater excretion of nitrogen during work than during rest. Furthermore, it shows why we need rest after work. In the first place, the circulation must have an opportunity to remove those waste products which accumulate in the working muscle faster than they can be carried off, and in the second place a fresh supply of force must be stored up in the way described before it is ready to be used at the command of the will.

Finally the assumption of a complex "contractile material" is in harmony with the results obtained by Fick &

Wislicenus and others regarding the force value of the nutrients, since it does not place the source of muscular power in the albuminoids alone but in the joint action of these and of non-nitrogenous matters.

It is possible that Kellner's results, if confirmed by further investigation, may modify this hypothesis somewhat. They at least suggest that when, under the influence of protracted work, the reserve of "contractile material" runs low, the protein of the muscle may be used to supply the deficiency.

In any case, it must be remembered that this hypothesis is only a provisional one. Much work remains to be done before we can have a full understanding of this important subject, and the chief value of such an hypothesis as this is to co-ordinate and arrange our knowledge, and serve as the basis for further research.

§ 3. Internal Work.

In the two previous sections we have been considering one particular form of work, viz., muscular exertion.

As pointed out at the beginning of this chapter, there are other forms of work which, though less obvious, are of equal or even greater importance, and we now turn our attention to these, grouping them under the convenient, if not strictly accurate, name of internal work.

The internal work of the body may be of three principal kinds: muscular work of the internal organs, production of heat, and of chemical changes.

Muscular Work of Internal Organs.—The activity of many of the most important internal organs involves considerable muscular action, *e. g.*, in the heart, the respiratory muscles, and the digestive apparatus. Of these, the work of the two former is tolerably constant, and makes pretty uniform demands on the latent energy supplied by the food, while the labor performed by the digestive apparatus is more variable, being relatively greater with a bulky than with a concentrated fodder, and is likewise greater at or near the time of feeding than at other times.

Henneberg's Experiments.—We have already learned that muscular exertion increases the excretion of carbonic acid, but not notably that of urea. Henneberg * has shown that the same is true of the work of the digestive organs, so far, at least, as the excretion of carbonic acid is concerned.

In one series of respiration experiments on sheep the animals were fed chiefly during the day, while in a second series they received most of their fodder in the night. The numbers in the following table give in grammes per day the results obtained on two sheep taken together:

FEEDING CHIEFLY BY DAY.

Number of Experiment.	FODDER (HAY).		CARBONIC ACID.		OF 100 PARTS CARBONIC ACID.	
	Day. Grms.	Night. Grms.	Day. Grms.	Night. Grms.	Day. Per cent.	Night. Per cent.
1 and 2..........	1,809	624	877	756	54	46
3 and 4..........	1,824	684	777	691	53	47
5 and 6..........	1,736	723	864	715	55	45
Average.......	1,790	677	839	721	54	46

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* Neue Beiträge, etc. 1871, p. 157.

FEEDING CHIEFLY BY NIGHT.

Number of Experiment.	Fodder (Hay).		Carbonic Acid.		Of 100 Parts Carbonic Acid.	
	Day Grms.	Night Grms.	Day Grms.	Night Grms.	Day. Per Cent.	Night Per Cent.
1 and 2..........	590	1,685	719	806	47	53
3 and 4..........	653	1,588	706	842	46	54
5 and 6..........	586	1,499	693	815	46	54
Average.......	610	1,591	706	821	46	54

The increased work caused by the feeding by day in one case, and by night in the other, resulted immediately in an increased excretion of carbonic acid.

It is probable that the difference observed in these experiments is chiefly the expression of the amount of work involved in chewing and rumination, since the alimentary canal always contains more or less fodder; but at the same time it gives us a useful hint of the amount of work required in the digestion of the bulky fodder of herbivorous animals.

Saving of Work by Concentrated Fodder.—A certain amount of work by the digestive organs is, of course, necessary and unavoidable, but it is evident that the amount of this work will be reduced by the use of as concentrated fodder as possible.

That is, the less the proportion of indigestible matters contained in a fodder, the less of the fodder will have to be eaten and worked over by the animal in order that it may obtain the amounts of the several nutrients which it requires. If we could eliminate the indigestible matters entirely from the fodder of an animal, we should effect the greatest possible economy of work by the digestive organs, and could produce an equal nutritive effect with a correspondingly smaller amount of digestible nutrients, since, as explained on p. 203, the production of work of any kind implies a destruction of the constituents of the body, which loss must finally be supplied by the food. Such an extreme case is purely suppositious, but obviously, the nearer we approach to it by the use of fodders containing a large proportion of digestible matter, the greater will be the saving of work, although we have no accurate data regarding the amount of the saving which could thus be made. In Miller's system of exclusive meal-feeding, it is probable that a portion, at least, of the saving in fodder is due to the less amount of work imposed on the digestive organs.

In practice, however, considerations of profit come in to modify the conclusions just drawn.

As a general rule, a given number of pounds of digestible matter can be had more cheaply in the form of coarse fodder, such as hay, straw, etc., than in the more concentrated fodders, like the grains, which contains less indigestible matter. Moreover, ruminating animals are adapted by nature to extract the nutritive matters from coarse fodder as completely as possible, so that it is obvious that under some circumstances it may be more profitable to feed almost exclusively coarse fodder (in wintering stock, for example), while in other cases, *e. g.*, fattening, where a rapid production is desired, the greater cost of concentrated fodders may be more than covered by the economy of digestive labor and the consequent saving of material which they cause.

Production of Heat.—The continual chemical changes going on in the body, like similar changes outside the body, give rise to a liberation of heat. Indeed, all the force conveyed to the body by the food leaves it either as motion or heat, all the actions of the internal organs, all the molecular labor of the nervous and other tissues, etc., being finally converted into heat. It has been estimated by eminent authorities that, in man, of the total energy represented by the food, from four-fifths to five-sixths takes the form of heat. This production of heat, of course, implies a corresponding consumption of food-material, just as the production of heat in a stove implies the consumption of fuel; so that it is evident that any change in the amount of heat set free has a direct effect on the demands of the body for food and on the results of feeding.

Vital Heat.—The bodies of warm-blooded animals (birds and mammals) maintain a very constant temperature at all times, in spite of great variations in the temperature of their surroundings. The production of *vital heat*, as it is called, by the oxidation of food-elements, and the losses of it to which the body is subject, are so balanced as to result in keeping the temperature of the body at from 95° to 104° F., a variation of more than a degree or two from the normal temperature of an animal indicating serious disturbance of the organism.

This regulation of the vital heat appears to be effected in two ways: first, by variations in the loss, and second, by variations in the production. The chief sources of loss of heat by the body are:

1. Conduction and Radiation from the Skin.
2. Evaporation of Water from the Skin and Lungs.
3. Warming of the Ingesta (Food and Drink).

These we will take up in their order and consider how in each case the balance of the vital heat is kept up.

Conduction and Radiation from the Skin.—This is one of the principal sources of loss of heat by the body, and also the one which is most susceptible to regulation. Henneberg,* in his respiration experiments on sheep, already cited, estimates that the total amount of heat produced by the animals experimented on was applied as follows:

To warming the ingesta	4.0	per cent.
" " " inspired air	4.2	"
" evaporation of water	26.7	"
" supply loss by radiation, etc.	65.1	"

Experiments on man have given very similar results.

Plainly, the greater the amount of blood passing through the vessels of the skin, the more heat will be lost, while, on the other hand, a diminution in the current of blood will check the loss of heat.

Now when the skin is exposed to cold, as, for example, to cold air or to the water of a cold bath, the capillaries of the skin are contracted and the blood-vessels of the viscera expanded, thus diverting a portion of the blood from the former to the latter and sometimes causing a rise of temperature in the interior of the body.

Conversely, under the influence of warmth the capillaries of the skin dilate, admitting more blood, and thus effecting a cooling of the latter. To this is to be added the loss of heat by the evaporation of the perspiration, to which attention will be called on subsequent pages.

In this manner the loss of heat from the surface of the body is regulated in accordance with the external temperature, but there are numerous experiments which show that under such circumstances the *production* of heat also varies, though we have but little knowledge of the means by which these variations are effected. It has been shown by numerous observations on rabbits, guinea-pigs, and cats that, in warm-blooded animals, exposure to cold largely increases both the consumption of oxygen and the excretion of carbonic acid, thus showing a greater activity of the chemical processes in the body and presumably an increased production of heat, while warmth, on the other hand, has the converse effect, diminishing the amount of chemical change in the body.

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* Neue Beiträge, etc., 1871, p. 227.

The following selection from the results obtained by Theodor * in an extensive series of experiments on a cat will serve to illustrate these facts. Each experiment lasted six hours.

Temperature. Deg. Cent.	Carbonic acid excreted. Grms.	Oxygen taken up. Grms.	Temperature. Deg. Cent.	Carbonic acid excreted. Grms.	Oxygen taken up. Grms.
−5.5........	19.83	17.48	+12.3......	17.63	17.71
−3.0........	18.42	18.26	+16.3......	15.73	14.74
+0.2........	18.24	19.95	+20.1......	14.34	12.78
+5.0........	17.90	14.82	+29.6......	13.12	10.87

In some of these experiments considerable motion on the part of the animal took place, which may have influenced the result, and Voit † therefore executed a series of similar experiments on a man. The man weighed about 156 lbs., and, after having been exposed for some time to the temperature whose effect was to be observed, passed six hours in the respiration apparatus fasting and in complete rest. In this time he excreted the following quantities of carbonic acid and nitrogen:

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* Zeit. f. Biologie, XIV., 51.

† Ibid., XIV., 57.

Temperature. Deg. Cent.	Carbonic acid. Grms.	Ureal nitrogen. Grms.	Temperature. Deg. Cent.	Carbonic acid. Grms.	Ureal nitrogen. Grms.
4.4	210.7	4.23	23.7	164.8	3.40
6.5	206.0	4.05	24.2	166.5	3.34
9.0	192.0	4.20	26.7	160.0	3.97
14.3	155.1	3.81	30.0	170.6	....
16.2	158.3	4.00			

The increased excretion of carbonic acid in the cold as compared with an ordinary temperature of 14° to 15° C. (about 60° F.) is as marked in these experiments as in the preceding ones, but above that temperature a slightly increased excretion was observed. The excretion of nitrogen is seen to vary in the same way, though to a small extent, indicating an increased protein consumption as a result of exposure to a low temperature.

These results show plainly how great an influence the temperature of its surroundings may have on the amount of fodder required by animals, and confirm the conclusion drawn from many practical experiments, that it is desirable to protect animals from extreme cold.

In conclusion, it should be said that the action of a low temperature of the surrounding medium appears to be, in the first place, on the nerves, and that only through them does it cause a greater activity of the chemical processes in the body and an increased production of heat.

It has been shown by Pflüger that when this action of the nerves is hindered, the activity of chemical change in the body is increased by heat and decreased by cold, just as many chemical processes outside the body are, and as is the case normally in cold-blooded animals.

Evaporation of Water.—An important regulator of the temperature of the body is the evaporation of water, especially from the skin.

In the conversion of any liquid into vapor, a very considerable amount of heat is absorbed, and becomes *latent* in the vapor. This absorption of heat during vaporization may be rendered evident to the senses by wetting the hand with some volatile liquid, such as alcohol or ether, and moving it through the air to hasten evaporation. In the same way, the evaporation of water from the skin, which is constantly going on, cools the latter; and though the effect is less noticeable than with a more volatile liquid, on account of the greater slowness of the evaporation, the total amount of heat thus abstracted from the body is very considerable, amounting, according to Henneberg (p. 231), in the case of sheep, to nearly 27 per cent. of the total loss of heat.

The conversion of one gramme of water at the temperature of the body into vapor of the same temperature requires 580 heat units, an amount equal to that produced by the combustion of 0.148 grammes of organic matter having the composition of starch, and corresponding to an excretion of 0.241 grammes of carbonic acid. In the experiments by Henneberg just mentioned, the average daily excretion of water from lungs and skin was 881.7 grammes, which, according to the above figures, required for its evaporation as much heat as would be produced by the combustion of 130.5 grammes of starch, while the average amount of carbhydrates digested per day was 464.3 grammes. Consequently, if the loss of heat by evaporation was supplied by the combustion of these substances, about 28 per cent. of them was thus consumed.

Such results as this, of which many might be cited, show us plainly both the importance of the process of evaporation as a regulator of the vital heat, and the great waste of fodder that may be caused by an undue increase in the perspiration.

The regulation of the temperature of the body by the perspiration, especially the sensible perspiration (sweat), is too familiar to require more than a simple mention; but the effect of increased perspiration in augmenting the excretion of carbonic acid is of greater importance for our present purpose. This effect is shown in these same experiments by Henneberg.

In the following table his results are arranged according to the amount of carbonic acid excreted. The numbers refer to the two animals taken together:

Temperature of stall. Deg. Cent.	Hay fed. Grms.	Water drunk. Grms.	Carbonic acid excreted. Grms.	Water evaporated. Grms.	Urinary nitrogen. Grms.
9.3......	2,508	2,757	1,468	1,268	14.81
12.7......	2,085	(?)	1,508	1,578	15.42
14.1......	2,275	3,193	1,525	1,601	16.91
13.6......	2,241	(?)	1,548	1,680	15.59
13.7......	2,459	3,038	1,579	1,750	15.56
13.7......	2,443	3,876	1,633	1,650	16.02

It is evident at once that in every case but the last an increased evaporation of water and an increased excretion of carbonic acid accompany each other; but whether the latter is a result of the former can be determined only after the possible influence of all the other factors which influence the excretion of carbonic acid has been considered. These are, in this case, the amount of food, the amount of water drunk, and the temperature.

That the amount of food has an important influence on the amount of carbonic acid excreted is a well-established fact, and is well illustrated by a seventh experiment on the same two sheep, in which all food was withheld for a single day. The carbonic acid excretion sank at once to 837 grammes, or scarcely more than half that previously observed.

In these six experiments, however, although the amount of fodder eaten varied somewhat, no connection can be traced between its amount and that of the carbonic acid.

The same is true of the amount of water drunk, while the lowest temperature (*i.e.*, the one which should cause the greatest activity of the oxidations in the body) coincides with the minimum of carbonic acid.

We must therefore conclude that there is a connection between the carbonic acid excretion and the evaporation of water, and that an increased evaporation causes more material to be oxidized in the body, in order to make good the resulting loss of heat.

Henneberg's experiments are the only ones which we yet possess on this important subject, but they suffice to show its practical importance and the desirability of further experiments in the same direction.

A direct influence of the amount of water evaporated upon the protein consumption does not seem to be indicated by these experiments.

Warming Ingesta. A considerable quantity of heat (according to Henneberg, about 4 per cent.) is consumed in raising the food and drink of an animal to the temperature of its body. Of this amount, by far the larger part is used in warming the water of the ingesta, both on account of its large amount and because a greater quantity of heat is required to increase the temperature of a pound of water one degree than is sufficient to effect the same change in a pound of any other substance.

The effect of excessive drinking on the production of flesh and fat has already been mentioned in the two preceding chapters, and there can be little doubt that a part, at least, of this effect is due to the demand for heat thus made on the system.

The last line of the table on p. 235 affords an illustration of the influence of the amount of water drunk on the excretion of carbonic acid. Although the quantity of water evaporated is less than in the two preceding cases, more carbonic acid is excreted, evidently on account of the considerably larger amount of water drunk. It is noticeable that the urinary nitrogen in this experiment is also more than in most of the others.

Further examples of the influence of the quantity of water drunk upon the decomposition of matter in the organism might be given, but the few results which have as yet been reached in this direction, while they afford important practical hints, are still so meagre that no very extended conclusions can be based on them.

Practical Conclusions.—In the foregoing pages we have seen that the production of heat makes large demands on the food supply of an animal, and that various circumstances may influence the amount of heat produced and thus effect an economy or a waste of fodder. There remains to be considered the practical application of these facts to the feeding and care of cattle.

Temperature of Stable.—It is evident that the warmer the air of the stable is kept the less heat the animals will lose by radiation, and consequently the greater will be the saving of fodder effected. If this were the only circumstance to be considered, the greatest economy would result from keeping the surroundings of the animal at the same temperature as its body, for then no heat would be lost by radiation.

A high temperature, however, tends to increase the perspiration, which, as we have learned, demands considerable heat for its evaporation; so that the saving effected by the diminished radiation consequent on a high temperature may be more than counterbalanced by the loss due to the greater amount of perspiration evaporated. To this is to be added the fact that the animals are also led to drink more water, thus still further increasing, or tending to increase, the consumption both of protein and fat in the body.

It thus becomes evident that the most favorable balance between these two opposing factors, and consequently the most economical production, may take place at a medium temperature, and this conclusion is one which accords with the general experience of farmers.

That the least expenditure of material by the body takes place at a medium temperature is very clearly shown by Voit's experiments, cited on p. 233.

Finally, the question of profit comes in. Warming the stable in winter involves a certain amount of expense; leaving it cold also involves a certain amount of expense, viz., the cost of the excess of fodder required by the animals. It is a question to be settled by the circumstances of each particular case which method of procedure is, on the whole, more profitable.

Amount of Drink.—As already pointed out, excessive drinking tends to increase the consumption of matter in the animal body, and thus to decrease the profits of the feeding. It therefore becomes the interest of the feeder to restrict the amount of water drunk by his animals to that required for health. This is estimated by Wolff at four pounds per pound of dry matter of the fodder for cattle, and two pounds for sheep, this amount including that present in the fodder. The more watery the fodder the less drink is necessary.

Naturally, the amount of water drunk will, in most cases, be left to the instinct of the animal, and regulated only by avoidance of those conditions which, like too large rations of salt, too high temperature of the stable, etc., increase the desire of the animals to drink.

Finally, there is no doubt that it would be advantageous, when practicable, to supply animals with water warmed at least somewhat above the freezing temperature, since it would seem that at least one chief object of the increased protein and fat consumption caused by excessive drinking is to produce heat to warm the water to the temperature of the body.

Still more is it desirable, in the wintering of stock, not to compel them to satisfy their thirst with snow or ice, since not only must these be warmed, but they must be *melted*, and the conversion of one pound of ice at 32° F. into water of the same temperature requires somewhat less than twice the amount of heat needed to warm one pound of water from 32° to the temperature of the body. All this heat comes directly from the combustion of tissue, and is just so much subtracted from the net results of feeding, and consequently from the feeder's pocket.

Cooking Fodder.—A portion of the advantage frequently claimed to result from cooking and steaming fodder undoubtedly arises from the fact that the fodder is eaten while still warm, and that thus a certain amount of the substance of the animal, which would otherwise be burned in warming the food, is rendered available for other purposes. This fact, in connection with the increased palatability of the fodder and the consequently greater consumption of it, probably explains the favorable results frequently obtained by means of this practice, and at the same time renders it evident that its profitableness must depend on circumstances. Under some conditions, the gain thus effected might repay the expense, while under other conditions it might be more economical to let the cattle warm their own food.

Production of Chemical Changes.—The food being, as already explained, the means by which supplies of force are introduced into the body, it is evident that any change taking place in the constituents of the food before they become part of the body by which any of the force which they contain is liberated, involves an equivalent loss to the organism. It is as if the fuel which is to drive the engine were partially burned before being put under the boiler.

Such changes actually take place in the food to some extent during digestion. For example, we have all along assumed that the carbhydrates yield grape-sugar in the alimentary canal, and all calculations of rations are based on that assumption. In the main it is probably correct; but it is known that portions of these bodies suffer still further decomposition and yield lactic acid. In this process some of the latent force of the carbhydrates appears as heat, and the resulting lactic acid and other products are less valuable to the body by just the amount of force thus liberated.

It was stated on page 64, that many good authorities consider that the digestion of cellulose consists essentially in a kind of fermentation. Little is known of this process, but it is not improbable that the small quantities of marsh-gas and hydrogen exhaled by ruminants have their source in it, and this fact indicates that a considerable part of the latent energy of the cellulose is liberated during its digestion.

This raises the question whether the various carbhydrates are equally valuable as nutrients—a question which has, as yet, received scarcely any attention. Their equivalency has been assumed and made the basis of the calculation of rations, simply because, in the lack of all evidence, this was the only practicable method. It is quite probable that this assumption does not involve any very great error, except, perhaps, in the case of cellulose; but the actual comparative value of these substances can be determined only when we know, *first*, how much latent energy each contains, and, *second*, how much of this energy is liberated during digestion.

This is, of course, equally true of the other classes of nutrients; * but the study of this subject can hardly be said to have begun, and the only object of mentioning it here is to show how provisional are our present methods of estimating the value of fodders, and to guard the reader against the error of considering them final and conclusive. They are of great value and have rendered very important service; it is certain that they are not grossly erroneous. At the same time, no good and much harm may come from an unintelligent overestimate of their accuracy and value.

The so-called *synthetic* chemical actions (that is, formations of complex substances from simpler ones), of which many have been shown to take place in the body, also demand a supply of force for their performance. Thus the production of the true "contractile substance" of the muscles (see p. 224), if such a substance exists, from protein and non-nitrogenous matter, must absorb and render latent large amounts of force coming from the simultaneous oxidation of other materials.

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* The few results which have been obtained on the albuminoids will be mentioned in another connection. They indicate that the vegetable and animal albuminoids are practically equivalent.

Such processes, however, have no significance to the feeder, since the force thus rendered latent is not withdrawn from the body, but is set free again in it when the complex substance is decomposed.

INFLUENCE OF STIMULANTS.—The influence of stimulants upon the chemical processes in the body has been but little investigated.

Voit's experiments on coffee * seem to indicate that this substance, at least, has practically no effect upon the protein consumption in the dog. On the other hand, it would seem that the oxidation of non-nitrogenous matters may be considerably affected by nervous influences, such as cold, stimulation of the skin, light, sound, etc. The fact that the excretion of carbonic acid is less during sleep also points in the same direction.

There appear to be no experiments on farm animals touching this point, but we may safely conclude from the facts known concerning other animals, as well as from practical experience, that nervous excitement, produced by rough treatment, noise, etc., is unfavorable to the best results of feeding.

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* "Untersuchungen über den Einfluss des Kochsalzes, Kaffee's, etc., auf den Stoffwechsel."

PART II.

THE FEEDING-STUFFS.

CHAPTER I.

DIGESTIBILITY.

A substance is said to be digestible if, when eaten, it can either be taken up directly by the absorbent vessels of the stomach and intestines, or is capable of being altered by the digestive fluids into substances which can be thus resorbed. The pure nutrients (except, perhaps, cellulose) may be considered to be wholly digestible, thus justifying their name, but as they occur in feeding-stuffs various circumstances conspire to prevent their entire digestion.

In the first place, as has already been more than once pointed out, our methods of fodder analysis are very imperfect, and serve only to divide the substances contained in the fodder into groups of more or less similar matters. All the nitrogenous matters are—or have hitherto been—included under the albuminoids, all the substances soluble in ether under fat, etc., while the nitrogen-free extract, being determined by difference, includes everything not belonging to the other four classes. It is evident that, besides real nutrients, each of these groups of substances may include many things which are wholly indigestible, and hence that, although pure protein, for example, may be wholly digestible, the "crude protein" of hay or straw may be only partially digestible, as is actually the case.

Furthermore, a substance which of itself is entirely digestible may be so enclosed in indigestible matters as largely or entirely to escape the action of the digestive fluids.

For example, seeds which are swallowed whole generally escape digestion, in spite of the fact that they consist largely of digestible matters, because their hard outer coatings shut up the latter in an impervious shell. Similarly, if the walls of a single cell are so hard and woody as to be unacted on by the juices of the alimentary canal, the contents of the cell may pass through the animal without being digested.

Finally, the relative quantities of the several nutrients in the fodder of an animal have a mutual influence on the amount of each digested. Thus, if a fodder be made over-rich in starch, the digestibility of the albuminoids is decreased, and, at the same time, a portion of the starch escapes digestion.

All these considerations render it obvious that a simple analysis is not sufficient to determine the value of a feeding-stuff, but that the digestibility of its constituents must be taken into account, either by direct experiment or by reference to the results of previous experiments.

In this chapter we shall consider such general principles as experiment has established regarding the digestibility, first, of coarse fodder, and second, of the concentrated bye-fodders, under the influence of various conditions, and in the following ones take up in detail the properties and digestibility of the more important feeding-stuffs.

In this connection it is important to distinguish between *digestibility* and *ease of digestion.*

By the digestibility of a feeding-stuff, or any ingredient of it, we mean the extent to which it is digested under ordinary conditions. If, in a digestion experiment, one-half of the crude protein of a certain feeding-stuff is digested, we express the digestibility of that nutrient by the number 50—that is, 50 per cent. of it was digested. If the digestibility of the crude fibre of a certain sample of hay is said to be 40, it means that 40 per cent. of it was digested. These numbers, expressing the percentage of the several nutrients of a fodder which is digestible, are called *digestion coefficients.*

In general, a high digestibility will naturally accompany easy digestibility, but this may not always be the case, and the two conceptions are entirely distinct.

§ 1. DIGESTIBILITY OF THE NUTRIENTS OF COARSE FODDER.

By the term "coarse fodder" we designate the various kinds of grass, hay, and straw, corn-fodder, stover, and, in short, all kinds of forage, whether fed green or dry. Coarse fodder commonly consists of the stalks and leaves of the plants, and is rich in woody fibre. Under ordinary circumstances it forms the bulk of the fodder of farm-animals, with the exception of the hog.

In this section we shall consider the digestibility of the several nutrients of coarse fodder when this is fed exclusively, taking up subsequently the influence of the quality of the fodder and of the presence of concentrated bye-fodders on the digestibility of the ration.

The Weende Experiments.—The foundations of our knowledge of the digestibility of feeding-stuffs were laid by the labors of Henneberg & Stohmann, at the Weende Experiment Station near Göttingen. Their experiments began in the year 1858, and in 1860 they published their first results, under the title "*Beiträge zur Begründung einer rationellen Fütterung der Wiederkäuer*," of which a second volume appeared in 1863–64. Further experiments were made in 1863–64 by G. Kühn, H. Schulze and Aronstein,* under Henneberg's direction, and in 1865 by Henneberg.†

All these experiments were made on mature oxen, and gave results regarding the digestibility of feeding-stuffs, particularly of coarse fodder, which subsequent investigations on these and other animals have served only to confirm, while they still form the basis of our feeding standards for oxen.

To these same investigators is likewise due the credit of developing and perfecting methods of experiment adapted to such researches, and which can hardly be said to have existed before, so that the Weende experiments may be considered to mark the beginning of a new era in the science of feeding.

Since their publication innumerable feeding experiments have been made, involving determinations of the digestibility of various feeding-stuffs, the results of which, in all important points, have been the same as those reached in Weende. It is far beyond the scope of this work to give even a partial account of these experiments, and we must content ourselves with selecting a few results to illustrate each point as it is brought up.

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* Jour. f. Landwirthschaft, 1865, p. 283; 1866, p. 269, and 1867, p. 1.

† Neue Beiträge, etc., Heft 1, p. 287.

Crude Fibre Digestible.—As has been already stated in a preceding chapter, a portion of the crude fibre of coarse fodders is digestible. This fact is so well ascertained, and has been so uniformly observed, that no special proofs of it need be brought forward here. The amount digested varies, according to the quality of the fodder and other circumstances, from 25 per cent. to as high as 70 per cent. of the total quantity.

The ruminants, in particular, have the power of digesting large amounts of crude fibre, a power due, doubtless, to the great extent of their alimentary canal and the length of time during which the food remains in it. They are hence especially adapted to the consumption of coarse fodder, such as hay and straw, and can extract from it considerable quantities of nutrients, while the horse stands considerably below them in this respect, and the hog seems, like the carnivorous animals and man, to be able to digest only young and tender fibre, such as is found in roots and in young and juicy green fodder.

The Digested Portion is Cellulose.—The "crude fibre" obtained in analysis is a mixture of cellulose and "lignin," but the digested portion has been shown to consist of cellulose only, which has exactly the composition of starch (p. 39) and therefore is assumed to have the same nutritive value as the latter.*

This fact has been deduced by a comparison of the elementary composition of the crude fibre of the fodder and of the excrement, as in the following example—an experiment made at Weende in 1860–61.

The fodder was wheat-straw, and 52 per cent. of its crude fibre was digested, while 48 per cent. was found in the excrement. The original crude fibre of the fodder and that of the excrement had the following composition respectively :

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* Compare page 241.

	Fodder.	Excrement.
Carbon	45.4	48.1
Hydrogen	6.3	6.8
Oxygen	48.3	45.1
	100.0	100.0

The following calculation gives us the composition of the digested portion :

	Carbon.	Hydrogen.	Oxygen.
In 100 parts of crude fibre of fodder...	45.4	6.3	48.3
" 48 " " " dung....	23.09	3.26	21 65
Difference = 52 parts of digested crude fibre	22.31	3.04	26.65
In 100 parts of digested crude fibre....	42.9	5.7	51.4
" " cellulose	44.4	6.2	49.4

The above numbers are simply intended to illustrate the method of calculation ; in other and later experiments a much closer correspondence with theory has been obtained. For example, the average of eleven experiments made in Weende in 1863 64, on various kinds of coarse fodder, and with every precaution, was the following, which corresponds as closely as can be expected in such experiments with the composition of pure cellulose :

	Digested.	Pure cellulose.
Carbon	44.27	44.4
Hydrogen	6.31	6.2
Oxygen	49.42	49.4

In these experiments the true cellulose in fodder and excrements was determined by a method proposed by F. Schulze, and from the data thus obtained the absolute amounts of cellulose digested in each experiment were calculated. The results were practically identical, as the following table shows, with the amount of crude fibre digested, thus furnishing another proof that the latter consisted of cellulose.

No. of Experiment.	Crude fibre digested. Lbs.	Cellulose digested. Lbs.	Difference. Lbs.
1	2.01	2.12	+0.11
2	1.91	2.16	+0.25
4	3.92	3.87	−0.05
5	4.63	4.47	−0.16
6	4.81	4.55	−0.26
7	4 37	4.02	−0.35
8	4 38	4.13	−0.25

By no means the whole of the cellulose of coarse fodder is digested, but its percentage digestibility is considerably greater than that of the "crude fibre."

Nitrogen-free Extract.—While a part of the crude fibre is always digested, especially by ruminants, a part of the so-called nitrogen-free extract, on the other hand, is not digested, or is at least, even if present in an easily soluble form, not resorbed, but excreted with the dung.

Compensation.—It is a noteworthy fact that a *compensation* takes place between the digested portion of the crude fibre and the undigested portion of the nitrogen-free extract. That is to say, these two quantities are always nearly equal, so that the amount of the nitrogen-free extract found by analysis *is an approximate measure of the digestibility of the total non-nitrogenous matters of the fodder, exclusive of fat** (*i. e.*, crude fibre + nitrogen-free extract).

This fact, however, is only true in a general way and on the average. In particular cases considerable variations are not infrequent, so that the quantity of non-nitrogenous substance digested varies from sometimes 120 per cent. to as low as 80 per cent., or even less, of the amount of nitrogen-free extract found by analysis, the theoretical number being, of course, 100 per cent.

It has been observed in several cases that the exactness of the compensation between the digested crude fibre and the undigested extract is influenced by the digestibility of the crude fibre.

Thus Stohmann,† who was the first to call attention to this fact, obtained in experiments on goats, the following figures for meadow hay:

	Hay No. 1.	Hay No. 2.	Hay No. 3.	Hay No. 3. (Another animal.)
Digestible fibre and extract in per cent. of nitrogen-free extract...	97	86	82	73
Digestibility of crude fibre........	63.6	58.0	51.0	44.6

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* The fat is sometimes included. Its amount is so small as to make little difference practically.

† "Biologische Studien," 1 Heft, p. 72.

Here it is evident that with increasing indigestibility of the crude fibre the amount of digestible non-nitrogenous matters falls more and more below the quantity of nitrogen-free extract, while only in the first case are the two approximately equal.

Other investigators have confirmed this result, and it has also been shown that the decrease in the digestibility of the total non-nitrogenous matter is, at least in some cases, less rapid than that in the digestibility of the crude fibre.

The younger and more tender a fodder is, the smaller is generally its percentage of crude fibre, and the greater is the digestibility of the latter. As a consequence, the whole amount of non-nitrogenous matters digested from such a fodder is generally larger, in comparison with the quantity of nitrogen-free extract, than is the case with one cut at a more advanced period of growth.

As an example of this may be mentioned some experiments on sheep made by Wolff, at Hohenheim, in which the animals were fed with green clover cut at four different periods of growth, No. 1 being the youngest and No. 4 the oldest. The first line (*a.*) of the table gives the percentage obtained by dividing the quantity of non-nitrogenous matter actually digested by the amount of nitrogen-free extract found by analysis, and hence shows how much the amount actually digested varied from the theoretical amount. The second line (*b.*) gives the percentage of the crude fibre which was digested.

	No. 1.	No. 2.	No. 3.	No. 4.
(*a.*)	111.9	105.5	101.8	88.5
(*b.*)	60.0	53.0	49.6	38.8

In No. 1 and No. 2, whose crude fibre was easily digestible, the actual amount of non-nitrogenous nutrients digested was greater than that calculated; in No. 3 the two were nearly equal; in No. 4, where the crude fibre was less digestible, it was only 88.5 per cent. of the theoretical amount.

It is obvious, from such results as these, that while the compensation between digested crude fibre and undigested nitrogen-free extract may be an aid in forming an estimate of the digestibility of a fodder, it is not sufficiently close to serve as the basis of exact calculations.

Recent experiments on the horse, to which reference will be made in subsequent pages, have shown that crude fibre is less digestible by this animal than by ruminants, and that consequently this compensation only takes place in very young and tender fodder.

Composition of Digestible Portion of Nitrogen-free Extract.—It has been shown, by essentially the same method as that applied to crude fibre, that the digestible portion of the nitrogen-free extract has very nearly the composition of starch.

We may therefore assume that all the digestible non-nitrogenous substances of the fodder, with the exception of the fat, are, like starch itself, converted into sugar or sugar-like substances, and as such are resorbed and taken into the circulation.

Further exceptions to this rule are the small quantities of organic acids either contained ready formed in the fodder or produced during digestion from the carbhydrates.

The quantity of these, however, is very small, and we can,* in general, regard all the digestible non-nitrogenous matter of the fodder, except the fat, as composed of carbhydrates and as having the same functions in nutrition as sugar and starch have been proved to have in the experiments which have been detailed in Part I.

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* With the reservations made on p. 184.

Composition of Undigested Nitrogen-free Extract.—The part of the nitrogen-free extract which remains undigested is a mixture of various substances richer in carbon than the carbhydrates and having, as a whole, nearly the percentage composition of lignin, as given on p. 39.

It is therefore a matter of comparative indifference in fodder analyses, whether the lignin dissolves in the acid and alkaline liquids used to isolate the cellulose or remains with the latter as incrusting substance. In one case it appears in the results of analyses as part of the nitrogen-free extract, in the other, as crude fibre ; in both cases it reappears in the excrements and leaves the total quantity and quality of the digested nutrients the same, and the only effect of a variation of this sort would be on the compensation between the undigested extract and the digested fibre.

The Aqueous Extract.—From the numerous experiments executed in Weende on oxen and sheep, the law has been deduced that the total quantity of solid matter that can be extracted from a fodder by boiling water, *i. e.*, the aqueous extract, is a measure of the digestible portion of the nitrogen-free extract. In single cases, however, considerable variations from the rule were observed on both sides of the average, amounting to as much as 14 per cent.

This method of judging of the quality of coarse fodder has not found any general application, for the reason that no necessary connection exists between the digestible nitrogen-free extract and the amount of substances soluble in water, since the latter includes not only non-nitrogenous matters but also larger or smaller quantities of protein and ash.

The rule is to be considered as, at best, a purely empirical one, which, to be sure, has some value for practical purposes, since in general the digestibility of a coarse or green fodder is greater the more solid matter can be extracted from it by boiling water, but to which no scientific value can be attached.

Crude Fat.—That the crude fat, or rather the ether extract, of the coarse fodders is a mixture of the most various substances, some of which are digestible and some indigestible, has been already explained. The chlorophyll, or green coloring matter of plants, is soluble in ether, but seems to be entirely indigestible, and the wax-like substances most probably belong to the same category.

It is therefore to be expected that the digestibility of the crude fat will be very different according to the kind and quality of the fodder. It is always greater in young and tender plants than in older ones, and it has also been observed that the crude fat of clover hay and of the straw of the legumes is generally more digestible than of that of meadow hay and the straw of the cereals.

Crude Protein.—The digestibility of crude protein in the various kinds of coarse fodder is subject to greater variations than that of almost any other constituent. Of the protein in clover hay and meadow hay, *e. g.*, a quantity varying, according to circumstances, from 35 per cent. to 75 per cent. of the total amount is digested. Generally the protein is more easily and completely digested the greater the percentage of it contained in the fodder, *i. e.*, the narrower the nutritive ratio. At the same time, the quantity and quality of the crude fibre has an influence on its digestibility.

Formulæ for Digestibility of Protein.—As we have seen, the digestibility of the non-nitrogenous matters of a coarse fodder, with the exception of the small quantity of fat which it contains, can be estimated from the results of analysis with sufficient accuracy for practical purposes, although not with scientific exactness.

Unfortunately, we have no such simple means of estimating the digestibility of the crude protein, although the attempt has more than once been made to supply one in the shape of a formula which should enable us to determine the digestibility of the crude protein of a fodder or of a ration by calculations based on its composition. These formulæ are, of course, all empirical, being founded on the results of as many feeding experiments as possible.

In view of the importance of protein in nutrition, and the great variability which experiment has shown to exist in its digestibility, the advantages to be derived from a correct formula of this sort are manifest. Nevertheless, none of the various formulæ which have been proposed have met with much favor, and it seems to be the opinion of the best authorities that it is yet too soon to attempt their formation.

All these formulæ aim to express the influence of the *chemical composition* of the fodder or ration on the digestibility of its protein—an influence which, though an important one, is by no means the only factor involved. As regards coarse fodder alone, they offer little advantage over the intelligent use of " digestion coefficients," and the less since the results obtained by their aid sometimes vary widely from the truth. In the case of a ration including considerable concentrated fodder, they seem to yield more exact results, and may prove of value to test the correspondence of a ration with the feeding standard, though they would be of but little use in compounding it. For this purpose, Stohmann's formula * is probably the best. It is the following:

$$p' = \frac{p}{1 + {}^{1}/_{9} \frac{s}{p}}$$

in which *p′* represents the digestible protein, *p* the total "crude protein," and *s* the total non-nitrogenous matters of the ration, including fat.

This formula makes the digestibility of the protein depend on the relative amounts of nitrogenous and non-nitrogenous nutrients, ignoring the influence of the amount of crude fibre. For this reason, it appears to give better results when applied to rations containing much concentrated fodder than when used for those composed exclusively of coarse fodder.

Finally, it must never be forgotten that these formulæ are entirely different from those of the mathematician. They do not, like those, express necessary truths, nor are they deduced from any well recognized natural law. They are *inductions*, and depend for their value on the number and accuracy of the observations upon which they are based. They may be of much value, but we must beware of trusting them too implicitly.

In regard to the digestibility of the protein of the coarse fodders, much that is of importance and can find application in practice has already been ascertained. On the more important kinds of coarse fodder large numbers of digestion experiments have been made, and we are able to give, as the results of these, coefficients expressing the average digestibility of the protein and the other ingredients of fodders as well as the range of variation observed. (See table in Appendix.) Some of these numbers are the average of more than fifty experiments, and therefore may be regarded as expressing, with considerable accuracy, the average digestibility of these substances. Others are the result of only a few trials, and hence are more liable to correction by the results of new experiments. Furthermore, we are able to judge, to some extent, of the digestibility of the protein in coarse fodder of different qualities and cut in various stages of growth, and of its digestibility by different kinds of animals, and have acquired some knowledge of the influence exerted upon it by the addition of concentrated feeding-stuffs to the ration. These points will be considered in the following sections.

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* **Landw. Versuchs-Stationen, XI., 401.**

Non-Protein.—Besides protein, coarse fodder, especially when cut young, is likely to contain a greater or less quantity of amides and other nitrogenous substances which we may, for convenience, designate as *non-protein.* These, so far as investigated, are soluble substances, and there is little doubt that they are easily and completely digested.

In all the statements of the previous paragraph reference was had to "crude protein," that is, to the total nitrogenous matters of the fodder. If account be taken of the amount of "non-protein" present, the digestibility of the true protein would, of course, be less; but how much less future investigations must show.

Ash.—*Phosphoric Acid.*—When ruminants are fed exclusively on coarse fodder, only traces of phosphoric acid are found in their urine. Only so much of the phosphoric acid of the fodder seems to be resorbed as is necessary for whatever formation of new tissue or of milk may take place; all the rest is excreted in the dung. On the other hand, the urine of the ruminants is, like that of the carnivora, very rich in phosphoric acid (20 to 45 per cent. of the ash) when the animals are fed exclusively on milk, or when full-grown animals are deprived of food for several days, so that they finally subsist upon their own flesh and fat. When calves and lambs are fed large quantities of grain, a greater or less quantity of phosphoric acid always appears in the urine.

The method of excretion of the phosphoric acid of the fodder therefore varies with the kind of feeding. According to Liebig, phosphoric acid is absent from the urine of herbivora because this liquid is usually alkaline and because the fodder usually contains much lime. Phosphate of lime is insoluble in alkaline fluids, and therefore phosphoric acid only appears in the urine when more is contained in the fodder than is sufficient to unite with the lime. Presence of magnesia, on the other hand, as Bertram * has recently shown, does not hinder the appearance of phosphoric acid in the urine, even though the latter be alkaline. When this takes place the urine is found to be free from lime.

Other Ash Ingredients.—Of the alkalies of the fodder 95 to 97 per cent., of the magnesia 20 to 30 per cent., of the lime only 2 to 5 per cent. and sometimes none, and of the sulphuric acid and chlorine, nearly the whole quantity, is excreted in the urine. The remainder of the above-named ash ingredients, so far as they are not held back and used in the body or in the production of milk, is found, along with the whole of the silica, in the dung.

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* Biedermann's Central-Blatt, Jahrg. 8, p. 108.

§ 2. CIRCUMSTANCES AFFECTING THE DIGESTIBILITY OF COARSE FODDER.

Influence of the Quantity of Fodder.—Feeding varying quantities per day and head of the same coarse fodder does not alter the percentage digestibility of the various nutrients. *E. g.*, if on a certain ration of hay an animal digests 76 per cent. of the total quantity of crude protein, and the amount of the ration be increased by one-third or one-fourth, 76 per cent. of the protein will still be digested, and the absolute quantity will accordingly be one-third or one-fourth greater.

This fact is shown by a number of the Weende experiments in which varying quantities of meadow hay or clover hay were fed to oxen, and also in experiments by Wolff,* at Hohenheim, on sheep fed on clover-hay.

In the latter experiments the following results were obtained:

Fodder per day. Pounds.	DIGESTED.			
	Protein. Per cent.	Fat. Per cent.	Crude fibre. Per cent.	Nitrogen-free extract. Per cent.
3	59	55	51	63
2	61	56	54	64
2	60	54	51	63

Some later experiments by the same investigator† have shown that the same fact is true of the digestibility of lucerne hay by sheep and likewise by the horse. The results on the latter animal were as follows:

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* "Die Versuchs-Station Hohenheim," p. 75.

† Landw. Versuchs-Stationen, XXI., 20.

Fodder per day. Pounds.	Digested.			
	Protein. Per cent.	Fat. Per cent.	Crude fibre. Per cent.	Nitrogen-free extract. Per cent.
17.6	74	..	33	70
22.0	73	..	37	71
26.4	77	..	43	72

A point to be considered is that all the observations hitherto made have been only on meadow hay, clover, and lucerne, of good or medium quality; but the same fact is, in all probability, true also for the more indigestible fodders, such as straw, chaff, etc.

This constancy is very important, and facilitates greatly the calculation of rations for the various purposes of agricultural practice.

Effect of Drying.—All the nutrients of dry coarse fodder are digested and resorbed to the same extent as when it is fed green.

Of the numerous experiments on this point, the following, by Weiske,* may serve as an example. They were made on two sheep, with lucerne, which was first fed green, and then after having been carefully dried without loss. The averages of the results on both animals were:

	Digested.			
	Protein. Per cent.	Crude fibre. Per cent.	Fat. Per cent.	Nitrogen-free extract. Per cent.
Green	79	33	38	68
Dry	78	34	50	65

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* Wolff: "Die Ernährung der Landw. Nutzthiere," p. 97.

With the exception of the fat, whose digestibility, as we have seen, cannot be determined very accurately, the several nutrients were equally well digested in the two cases.

This result, which has been fully confirmed by many other experiments, stands in apparent contradiction to the general experience of farmers.

It must be remembered, however, that it is only true when the green fodder and the hay are otherwise of exactly the same quality; when both are cut at the same time and from the same field, and when none of the leaves or other tender and especially nutritious parts are lost during the preparation of the hay.

These conditions are never completely reached in practice, especially in the making of clover or lucerne hay, and for this reason, and also because green fodder is commonly used at an earlier stage of growth than that which is converted into hay, a greater nutritive effect is generally observed with green fodder.

For the present we may pass over the question whether the large quantity of water which milking animals consume in green fodder exercises any considerable influence on the amount of milk produced, but the *digestibility* of the organic constituents of a fodder is in no way altered by simple drying in the air, provided it is executed without loss of parts of the plants.

On the other hand, the ordinary method of making hay involves a considerable loss of leaves, etc., and the product suffers not only in its quality, as shown by chemical analysis, but in its digestibility as well.

For example, in some experiments at Hohenheim, by Wolff, Funke, and Kellner,* the loss involved in the preparation of lucerne hay amounted to 7.13 per cent. of the dry matter, and the composition and digestibility of the resulting product, as compared with that obtained by drying the same material without loss, were as follows:

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* Landw. Versuchs-Stationen, XXI., 425.

	COMPOSITION.		DIGESTIBILITY.	
	Dried without loss.	Hay.	Dried without loss.	Hay.
Protein	17.00	14.94	71	67
Crude fibre	31.81	33.90	48	45
Nitrogen-free extract Fat	43.80	44.22	66	62
Ash	7.39	6.94	29	23
	100.00	100.00		

Effect of Storing.—The storing of fodder for a long time, even when all necessary precautions, such as a dry and airy location, etc., are observed, may decrease both its digestibility and palatability.

At least, this conclusion can be drawn from some experiments executed in Hohenheim.* Of the crude protein of a sample of rowen, 62 per cent. was found digestible directly after the harvest, while three months later 56 per cent., and in the following spring 54 per cent., of the total quantity was digested by the same animals. The digestibility of the crude fibre also decreased somewhat, while that of the other nutrients remained about the same. A similar fact was observed by Hofmeister† in regard to clover hay, and essentially the same results were also obtained in later experiments in Hohenheim.

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* Landw. Jahrbücher, II., 282.

† Landw. Versuchs-Stationen, XVI., 353.

In all the Hohenheim experiments, the chemical composition of the fodder remained substantially unchanged, and the deterioration showed itself in a diminished digestibility. Whether, however, the smaller nutritive value of hay and straw kept over winter, which is often observed in practice, even when the hay has apparently kept excellently, is caused by an essential alteration in the digestibility of the fodder, or is to be sought chiefly in the mechanical loss of the more nutritious parts, which always takes place to some extent, and in decreased palatability, must be left to future researches to decide.

Period of Growth.—Early cut forage is not only superior, other things being equal, to late cut, as regards its chemical composition, but it excells it in digestibility as well.

This fact is established by abundance of experimental evidence. In some experiments by G. Kühn,* oxen were fed with clover hay cut from the same field at three different times, viz.:

I. Cut May 20, just before flowering.
II. " June 7, in full bloom.
III. " " 20, end of flowering.

The composition and digestibility of the water-free substance of these hays were the following:

COMPOSITION.

	Protein. Per cent.	Crude fibre. Per cent.	Fat. Per cent.	Nitrogen-free extract. Per cent.	Ash. Per cent.
I.	19.56	25.30	2.25	45.52	10.10
II.	16.31	28.11	2.87	44.95	7.76
III.	13.19	28.80	2.86	48.37	6.78

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* Wolff: "Ernährung Landw. Nutzthiere," p. 106.

DIGESTIBILITY.

	Protein. Per cent.	Crude fibre. Per cent.	Fat. Per cent.	Nitrogen-free extract. Per cent.	Ash. Per cent.
I.	76	51	58	70	.....
II.	65	47	64	68	.....
III.	59	40	60	66	.....

In experiments made at Hohenheim on clover cut at four stages of growth and fed to sheep, a similar decrease of the digestibility with increasing age was observed, that of the protein falling from 75 to 59, and that of the crude-fibre from 60 to 39. Many other similar experiments might be cited.

Another circumstance which increases the feeding value of early cut forage is the fact that it is not only more digestible, but contains a much larger percentage of crude protein than is found in that cut later. The difference in the actual quantity of protein digested is thus larger in a two-fold ratio in early cut fodder. Thus, in the above-mentioned experiments by G. Kühn, the quantity of protein actually digested amounted, in the first case (I.), to 13.9 per cent. of the total dry matter of the fodder; in the last case (III.) to only 7.8 per cent.

These facts make it evident that the same kind of coarse fodder may differ greatly in its nutritive effect, according to the circumstances under which it is grown and harvested.

In considering these results, however, it is to be remembered that, as regards protein, the coefficients express the digestibility of the total nitrogenous matters, both albuminoids and non-albuminoids. As we have seen, recent investigations have revealed the presence of large amounts of "non-protein" in coarse fodder, especially in the earlier stages of its growth. This non-protein is, in all probability, entirely digestible, and it is easily to be seen that its presence might affect the correctness of the above results.

The only experiments touching this point are a few by Wolff * on sheep and on a horse, with hay cut from the same field in two different years. These gave the following digestion coefficients, *a* for total nitrogenous matter, *b* for true protein:

Fodder cut.	Sheep.		Horse.	
	a.	*b.*	*a.*	*b.*
April 24, 1874	79.1	73.3	....	....
May 13, "	71.1	64.3	....	....
June 10, "	69.1	64.2	....	....
May 14, 1877	73.3	59.1	68.8	52.1
June 9, "	72.1	66.7	66.1	59.6
" 26, "	55.5	51.9	61.8	58.7

These figures are somewhat conflicting as regards the digestibility of the true protein in fodder cut at different times, and it must be left for future investigations to decide how far the results which have been obtained for the total nitrogenous matter of coarse fodders are true of their actual protein.

Methods of Preparing.—While the various methods of preparing fodder for animals, such as steaming, ensilage, etc., may be accompanied by practical advantages, all the experiments hitherto executed show that the *digestibility* is not sensibly increased thereby.

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* Landw. Jahrbücher, VII., I. Supplement, p. 263.

Thus, in the experiments executed in 1862, at the Dahme Experiment Station, by Hellriegel & Lucanus,* it was found that the digestibility of rye-straw by sheep was not increased either by fermenting or cooking it. Experiments in Proskau, by Funke, gave the same results regarding the digestibility of the total dry matter and the cellulose of a mixed ration fed to milk cows.

Indeed, recent experiments at Poppelsdorf † showed a decreased digestibility of hay as a result of steaming. A rather coarse hay was fed to oxen, first dry, then steamed, and finally moistened with as much water as it took up when steamed. The following were the results:

	DIGESTIBILITY.				
	Total organic matter. Per cent.	Protein. Per cent.	Fat. Per cent.	Crude fibre. Per cent.	Nitrogen-free extract. Per cent.
Dry.............	58	46	39	59	60
Steamed........	56	30	41	58	59
Moistened.......	54	39	38	54	57

Steaming and moistening seem to have affected the digestibility of the protein especially. It is possible that the large decrease observed may have been caused by an extraction of soluble nitrogenous matters, though care seems to have been taken to avoid this, but no *increase* of digestibility as a result of cooking is shown.

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* Landw. Versuchs-Stationen, VII., 242, 324, 387, and 467.

† Hornberger: Landw. Jahrbücher, VIII., 933.

In these experiments the steamed fodder was purposely allowed to cool before it was used, in order to observe only the effect of cooking, and no preference for the steamed fodder on the part of the cattle was observed, but rather the reverse. In practice, however, the palatability of a fodder may often be very considerably increased by suitable preparation, and the animals thus induced to eat larger quantities of a fodder not perhaps agreeable to them in its natural state. It would seem that some gain must also accrue from *warm* fodder (see p. 239). The preparation of fodder may thus produce very favorable results in a practical point of view, although the quantity of nutrients which an animal extracts from a given amount of dry substance is no greater in one case than the other.

As in the case of coarse fodder, the digestibility of concentrated fodders is not increased by the method of preparation. This is shown, *e. g.*, by experiments made in Möckern on feeding bran to oxen; not only was the digestibility not increased, but, on the contrary, decreased more or less by boiling, addition of leaven and production of incipient fermentation, and still more by successive treatment with alkalies and acids. The effect was greatest on the protein and least on the non-nitrogenous constituents.

Digestibility by Different Kinds of Animals.—The different kinds of ruminating animals, as oxen, cows, sheep, and goats, digest the same fodder equally well.

As a mean of about forty single determinations, the digestibility of all the constituents of meadow hay is found to be about 2 per cent. greater in the case of oxen and cows than in that of sheep, while, in a still greater number of experiments, clover-hay or green clover is found to be digested 2 to 3 per cent. better by sheep than by oxen and cows. The differences, small in themselves, thus fully compensate each other in the two kinds of hay. In feeding-experiments on goats, likewise, average digestion coefficients have been observed in all experiments yet made.

In the case of a non-ruminating animal, like the horse, coarse fodder is less completely digested than by ruminants.

A large number of experiments on the comparative digestibility of various feeding-stuffs by the horse and sheep have lately been executed at the Hohenheim Experiment Station, under Wolff's direction. A comparison of all the results yet obtained * leads to the following conclusions:

1. Meadow-hay is less fully digested by the horse than by sheep, the difference amounting to 11 to 12 per cent. of the water-free substance.

2. The crude protein of hay is nearly as digestible by the horse as by sheep. In the better qualities of hay experimented upon, the difference amounted to·4 to 6 per cent. of the total amount, while in some of the poorer sorts more was digested by the horse than by sheep. This appears to be the case not only with the total nitrogenous matters but also with the true protein (compare p. 265).

3. Of the non-nitrogenous constituents of hay, the nitrogen-free extract is slightly, and the crude fibre considerably better digested by sheep than by the horse. As a result, the nutritive ratio of the portion of the hay digested is narrower in the case of the horse than in that of sheep. As regards fat, all the experiments gave very low results for this nutrient, owing to the presence of a con-

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* Landw. Jahrbücher, VIII., I. Supplement, p. 97.

siderable quantity of biliary products, etc., in the excrements.

4. Of two kinds of lucerne hay, the protein and nitrogen-free extract were equally well digested by the horse and by sheep, while the crude fibre appeared to be relatively somewhat better digested than that of meadow hay.

5. The digestibility of straw (of winter wheat) was found to depend somewhat on the amount of mastication it received, but in general to be small. Under ordinary circumstances it seems to be hardly half as well digested by the horse as by ruminants.

6. Concentrated feeding-stuffs (oats, beans, and maize, the two latter soaked with water) are digested to the same extent by the horse and by sheep. Similar observations have been made regarding the digestibility of concentrated fodders by the hog.

All these conclusions apply, in the first place, only to the conditions of these experiments, but, at the same time, there is every reason to expect that they will be confirmed by subsequent investigation, at least in their main features.

Influence of Breed.—If the various species of ruminants digest their fodder to the same extent, we should still less expect to find important differences in this respect between the breeds of one and the same species.

In fact, repeated experiments in Dresden and Hohenheim have agreed in showing that, *e. g.*, Merinos, Southdowns, and the so-called Wurtemberg Bastard-sheep, both when store-fed and on an exclusive ration of meadow or clover-hay, as well as on a more or less rich fattening fodder, digest the same feeding-stuffs about equally well.

In these considerations we must not confuse the *digestibility* of a fodder with its *nutritive effect*. The latter may be very unequal in the different breeds, and is determined, on the one hand, by the appetite of the animal and the quantity of fodder which it can eat and digest day by day, and on the other hand, by the whole organization of the animal and its temperament and congenital peculiarities.

With this, however, the actual percentage digestibility of a fodder has primarily nothing to do. The latter is essentially the same in all breeds for the same fodder, it being, of course, assumed that there are no individual peculiarities of digestion to disturb the result.

Age of the Animals.—Even at different ages or in different stages of growth the digestive power for any given fodder seems to be nearly the same, provided that the animals are weaned from milk and that the fodder is agreeable in taste and sufficient in nutritive effect. This fact has been shown by experiments made in Hohenheim * on lambs of two races, and continued for nine months consecutively (from the fifth to the fourteenth month of their age), and which included both exclusive hay fodder and rich feeding with hay and grain. Recent experiments made by Weiske † on lambs, extending over about ten months, have given the same result.

It is of course possible that this constancy of digestive power would be less marked in case of a poor and difficultly-digestible fodder, but young animals, so long as they are capable of and inclined to rapid growth, cannot thrive on such a fodder; they consume a quantity insufficient for their normal nourishment, and must suffer under a long continuance of such treatment.

Individual Peculiarities have often a greater influence on the digestive process than the breed or even the species of the animal.

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* Landw. Jahrbücher, II., 219.

† Ibid., IX., 205.

Besides temporary disturbances of digestion and the weak digestion caused by old age, animals of the same species and breed and of the same age and live-weight often show constant differences in digestive power, which, however, seldom exceed 2 to 4 per cent. of the total dry matter of the fodder.

Greater differences in digestive power sometimes show themselves in single individuals which fall strikingly below other animals of the same age in development and live-weight. For example, a difference of 7 per cent. in the digestibility of the total organic matter, and of 15 per cent. in that of the crude fibre, was observed in such a case in Proskau. At the same time, however, it was found that those animals of a herd which attained the greatest live-weight in a certain time on a given kind of fodder did not always possess the greatest digestive power nor produce the most live-weight from the same weight of food. The greater or less appetite, and the quantity of fodder daily eaten, are much more important conditions of the increase in weight of growing or fattening animals than an increased digestive power.

Actually stunted animals, those which have been insufficiently nourished in youth, especially during suckling, have also generally a relatively weak digestive power in later stages of development. How far the latter can be strengthened by the manner of rearing still remains to be investigated.

Effect of Work on Digestion.—A question of some importance is the effect of the performance of work on the digestibility of the fodder. In the recent experiments at Hohenheim on the horse, already alluded to, this question was made the subject of investigation.*

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* Landw. Jahrbücher, VIII., I. Supplement, p. 73.

Two series of experiments were made. In the first, the daily ration consisted of 13.2 lbs. of oats, 11 lbs. of hay, and 3.3 lbs. of cut straw; in the second, of 16.5 lbs. of hay and 8.8 lbs. of beans. In the following tables are to be found the amount of work performed per day in each experiment, and the percentage digestibility of the several nutrients, reckoned on the total ration.

SERIES I.

Work performed per day. Kilogramme-meters.	Digestibility.				
	Total Organic substance. Per cent.	Protein. Per cent.	Fat. Per cent.	Crude fibre. Per cent.	Nitrogen-free extract. Per cent.
475,000	58.73	70.84	52.05	31.24	68 27
950,000	58.62	67.63	52.55	29.03	69.61
1,425,000	58.66	69.95	45.90	32.33	68.27
950,000	56.41	66.62	48.73	25.82	67.65
475,000	54.82	68.21	45.99	26.95	64.41

SERIES II.

600,000	60.04	77.46	24.00	38.55	66.80
1,800,000	58.48	75.00	12.61	34.73	67.30
600,000	57.69	74.60	10.12	34.50	66.05

In each series the digestibility decreases slightly toward the close, but this is obviously independent of the amount of work performed. It was probably caused by a deterioration in the quality of the hay consequent on keeping and handling.

In these experiments, then, the digestibility of the fodder was not affected by the amount of work performed.

Presumably, this is true in all cases, but these are the only experiments yet made on this point.

§ 3. Digestibility of Concentrated Fodders and their Influence on that of Coarse Fodder.

Method of Experiment.—The foregoing section shows clearly that the percentage digestibility of coarse fodder, so long as the latter forms the exclusive ration, is determined very largely by the chemical composition of its dry matter as affected by the time of cutting, weather, soil, manure, etc., while other circumstances, such as quantity, state of dryness, and method of preparation, as well as the kind, breed, and age of the animals, have very little influence upon it.

This is an important result, and one of practical worth in the calculation of the daily ration of an animal.

It is, however, still more important to investigate whether and how much the digestibility of the constituents of coarse fodder is altered by the addition of concentrated fodders, as well as to determine the digestibility of the latter.

In the nature of the case it is practically impossible to make direct experiments with concentrated fodders, since they are not suited for the requirements of herbivorous animals. The best we can do is to feed increasing quantities of any concentrated fodder along with a fixed quantity of coarse fodder of known digestibility, and ascertain the digestibility of the mixture as a whole. It is, of course, in most cases impossible to determine with certainty what portion of the digested nutrients comes from the coarse fodder and what from the concentrated fodder; but results may be reached which possess sufficient exactitude for the purpose of compounding rations.

If a concentrated fodder decreases the digestibility of the coarse fodder with which it is fed, we should expect that with a greater relative quantity of the former in the ration the decrease in the digestibility of the ration as a whole would be also greater.

We therefore proceed as follows: in a first period we determine the digestibility of the coarse fodder—hay, for example—when fed alone. In a second period we add to the hay a certain amount of the concentrated fodder in question—maize meal, for instance—and determine the digestibility of the mixture. In a third period we increase the relative quantity of meal very considerably, and determine the digestibility of this mixture.

Now, assuming the digestibility of the hay to have been the same in the second and third periods as in the first, we calculate, from our experimental results, the digestion coefficients for the maize meal in the second and third periods.

It is obvious that, if neither feeding-stuff has altered the digestibility of the other, these two sets of digestion coefficients ought to be the same within the limits of experimental error, and, in that case, we have not only proved this fact but have also determined the digestibility of the maize meal.

On the other hand, if the digestibility of either feeding-stuff has been diminished by the presence of the other, it is plain that our method of calculating the results will show an apparent decrease in the digestibility of the maize meal. In the case supposed it would be impossible to determine directly in which of the two feeding-stuffs the decrease took place, and the method of expressing the results would depend partly on the results of other experiments and partly on questions of convenience.

Some of the examples contained in the following paragraphs will, perhaps, make the method of calculation clearer, while they at the same time serve to elucidate some of the practical questions that arise.

These questions concern chiefly the influence of concentrated fodders on the digestibility of coarse fodder, and to them we shall devote most of our attention, since it is impossible, within the limits of this work, to notice the numerous experiments on the digestibility of the various concentrated fodders. For the results of the latter the reader is referred to the Appendix.

EFFECT OF ALBUMINOIDS.—E. Schulze & Märcker,* in Weende, have made experiments on the effect of a preparation of wheat-gluten containing 78 per cent. of albuminoids on the digestibility of meadow-hay. They experimented on sheep, and obtained the following results for the percentage digestibility of the hay, on the assumption that the gluten was wholly digested:

	Protein.	Crude Fibre.	Fat and nitrogen-free extract.	Total organic matter.
Hay alone.................	57	57	66	62
Hay and 119.4 grms. gluten..	53	58	67	63
Difference.............	−4	+1	+1	+1

A second experiment, with a larger amount of gluten, gave, on the same assumption, the following results:

	Protein.	Crude Fibre.	Fat and nitrogen-free extract.	Organic matter.
Hay alone.................	55	55	65	61
Hay and 262.2 grms. gluten.	49	61	61	60
Difference.............	−6	+6	−4	−1

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* Jour. für Landwirthschaft, 1871, p. 68.

The slight decrease in the digestibility of the protein of the hay becomes so exceedingly small, when calculated on the whole ration, as to be of no practical significance, while the gluten exerted practically no influence on that of the remaining nutrients. Thus, these results show not only that even these large additions of albuminoids to the fodder produced no essential alteration of digestibility, but also that the gluten was almost completely digestible.

Very similar results were obtained in a series of experiments, executed at Hohenheim,* on the digestibility of "flesh meal" by swine. It was fed in varying quantities along with potatoes. Assuming that the digestibility of the potatoes was not altered by the addition of the highly nitrogenous flesh meal, the following numbers were obtained for the digestibility of the latter:

Period.	Number of animal.	FED.		DIGESTIBILITY OF FLESH-MEAL.		
		Potatoes. Grms.	Flesh meal. Grms.	Protein. Per cent.	Fat. Per cent.	Organic substance. Per cent.
I.	2	4,500	190	95.1	82.3	93.4
I.......	3	5,000	210	97.0	87.5	96.1
II......	1	5,000	500	98.5	88.7	93.5
II......	4	4,500	450	98.9	88.5	90.9
II......	2	6,500	195	102 9	75.2	94.3
II......	3	8,000	240	96.4	90.7	86.9
III.....	1	7,500	225	91.4	83.3	87.8
III.....	4	7,500	225	98.6	89.6	90.4
Average.........		6,063	279	97.4	85.7	91.7

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* Landw. Jahrbücher, VIII., I. Supplement, p. 200.

Though the ratio between potatoes and flesh meal varied between wide limits, the digestibility of the latter, calculated on the basis of unaltered digestibility of the former, varied but very little, and rather increased than decreased in the experiments in which relatively most flesh meal was fed. Since the flesh meal contained no crude fibre or nitrogen-free extract, the digestibility of these ingredients of the potatoes could be determined directly in each experiment. It was found to be sensibly the same in all.

Obviously, the results of these experiments are *as if* the potatoes were equally well digested in all cases, and *as if* the above coefficients represented the digestibility of the flesh meal; and though this fact cannot, perhaps, be said to be absolutely proved, the practical result is the same as if it were, and we can make it the basis of calculations of digestibility in similar cases.

Nitrogenous Bye-Fodders.—By means of experiments made on the same plan as those just described, it has been found that for the ordinary nitrogenous bye-fodders, such as oil cake, cotton-seed cake, bran, beans, etc., digestion coefficients may be obtained, and that these coefficients remain nearly constant whatever the quantity of the fodder given, while the digestibility of the coarse fodder remains unaltered by the addition of the concentrated fodder.

This conclusion is drawn from the results of numerous digestion experiments in which increasing quantities of the concentrated fodder were fed along with meadow or clover hay. Such experiments have been made in Hohenheim, Möckern, and Halle, especially with oil cake, but also with crushed beans, rape cake, wheat bran, and cotton-seed meal, on sheep, goats, and oxen, with the results stated. In all probability, experiment would show that the same thing is true of other highly nitrogenous bye-fodders, *e. g.*, all kinds of oil cake, the legumes, brewers' grains, etc.

The results of these determinations of the digestibility of bye-fodders are included in Table II. of the Appendix. As the general result of the experiments, we can say that *nitrogenous bye-fodders do not decrease the digestibility of the coarse fodder with which they are used.*

The Grains.—The influence of the grains, *i. e.*, of concentrated fodders with a medium nutritive ratio (1 : 5–8), on the digestibility of coarse fodders has received comparatively little attention.

Oats have been the subject of experiments by Hofmeister & Haubner* and by Wolff† on sheep. In both investigations it was found that an addition of oats to the coarse fodder did not essentially alter its digestibility. Wolff obtained the following results, on the assumption that the digestibility of the coarse fodder (hay) was not altered:

Ratio of hay to oats.	Crude protein of oats digested. Per cent.
1 : 1.76	78.0
1 : 3.09	78.4
1 : 3.30	78.5

The constancy of the digestion coefficient for oats shows, as explained above, that the assumption of unaltered digestibility of the coarse fodder is probably correct, and can at least serve as a basis for the calculation of rations. Hofmeister & Haubner's results were, on the same assumption, as follows:

Ratio of hay to oats.	Crude protein of oats digested. Per cent.
1 : 0.18	74.0
1 : 0.44	74.1
1 : 0.75	67.3

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* Landw. Versuchs-Stationen, VI., 185 and 301.

† Landw. Jahrbücher, II., 288.

Here we have also a nearly constant coefficient for the protein of the oats, except in the last case, where a slight depression is observed, which may indicate an actual decrease in the digestibility of the hay. The oats used in Wolff's experiments had a considerably narrower nutritive ratio (1 : 5.16) than those used by Hofmeister & Haubner, (1 : 7.07), and it is quite possible that the slightly smaller digestibility in the latter case, as well as its decrease in the third experiment, is due to this cause.

The digestion coefficients of the other constituents of the oats, except those of crude fibre, whose digestibility generally shows considerable variations in all the grains, were nearly accordant in all the experiments.

The recent comparative experiments on the horse and sheep, made at Hohenheim, and to which reference has more than once been made, included determinations of the digestibility of oats, maize, and beans, when fed with coarse fodder. In no case was any noticeable influence of these feeding-stuffs on the digestibility of the coarse fodder observed.

Experiments in Weende by E. Schulze & Märcker * seem to indicate that when the nutritive ratio of the grain or of the whole ration is wide (1 : 8–10), the digestibility of the coarse fodder may be diminished. We shall presently see that feeding-stuffs rich in carbhydrates, especially roots, decrease the digestibility of coarse fodder. Grain with a nutritive ratio of 1 : 10, like that used in Weende, begins to approach roots in composition, and may produce a similar effect; but we may safely say that grain of good quality (nutritive ratio 1 : 5–6) produces no decrease in the digestibility of coarse fodder.

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* Jour. f. Landwirthschaft, 1875, 163.

EFFECT OF CARBHYDRATES.—All investigation goes to show that increasing the protein of a ration has no tendency to diminish the digestibility of the latter, but rather to increase it.

The carbhydrates, on the contrary, when added in large quantities to a ration, depress the digestibility of the crude fibre, and especially of the protein, to a considerable extent. This has been observed in numerous experiments on oxen, cows, sheep, and goats, both when pure carbhydrates were fed and when fodders containing large amounts of these substances were used.

Starch.—In the earlier Weende experiments this effect of starch on the digestibility of coarse fodder was observed, and the observation has been fully confirmed in later investigations.

Experiments of this sort have the advantage over many digestion experiments that it is possible to ascertain whether or not the starch is entirely digested. This substance is free from protein, and hence any decrease in the digestibility of the latter must fall exclusively on the rest of the fodder. The same is true of the crude fibre and fat, while as regards the nitrogen-free extract, it is easy to determine, by a microscopic examination of the excrements, whether any of the starch has escaped digestion. The results, therefore, possess no ambiguity.

The following table contains a summary of the results of experiments by Henneberg & Stohmann, E. Schulze & Märcker, Stohmann, and Wolff, compiled from Wolff.* The first column contains the name of the experimenter; the second, the amount of starch fed, expressed in per cent. of the dry matter of the remaining fodder; the third shows the character of the other fodder; the fourth and fifth express the decrease in the digestibility of the protein and crude fibre in per cent. of the quantity of each which was digested when the starch was withheld.

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* "Ernährung Landw. Nutzthiere," pp. 139–145.

No.	Authority.	Starch in per cent. of other fodder.	Fodder, exclusive of starch.	DECREASE IN DIGESTIBILITY OF	
				Protein. Per cent.	Crude fibre. Per cent.
1....	Henneberg & Stohmann.	15	Clover-hay, straw, and beans.	7	[illegible]
2....	" " "	18		11	7
3....	" " "	29		21	15
4....	" " "	9	Same with more beans.	3	4
5....	" " "	9		4	2
6....	Schulze & Märcker.	25	Hay.	41	10
7....	" " "	25	Hay and beans.	20	13
8....	Stohmann.	15	Hay.	12	12
9....	"	69	"	44	7
10....	"	15	Hay and oil-cake.	9	10
11....	Wolff (experiments on hogs).	15	Barley.	0	
12 ...	" " "	31	"	11	..

Two things are shown by this table: first, the greater the amount of starch which is added to a ration, the more is the digestibility of the protein and crude fibre decreased, *e. g.*, in experiments 1, 2 and 3, or 8 and 9; second, the richer the original ration is in protein, the less is the depression caused by a given quantity of starch, *e. g.*, Experiments 6 and 7.

But this amounts to saying that the protein and crude fibre of a ration are better digested the narrower the nutritive ratio of the latter, a fact which, it will be remembered, we have already noticed in the case of hay, and which Stohmann has made the basis of his formula (p. 256) for calculating the digestibility of the protein of a ration from its chemical composition. A large number of results seem to indicate strongly that this is a general law, of which the experiments cited above are only special cases, and that the non-nitrogenous matters of hay, *e. g.*, as truly depress the digestibility of its protein and fibre as does the addition of starch. The only difference is that we cannot abstract the non-nitrogenous matters from the hay and observe the digestibility of the other constituents, but must determine the digestibility of the hay as a whole.

The statement that starch decreases the digestibility of other fodder, then, is simply a practically convenient way of stating the result in this particular case.

Sugar.—Not many experiments on the influence of sugar on the digestibility of rations have been made; but those which have been executed show, as was to be expected, that widening the nutritive ratio of a ration by means of sugar produces essentially the same result as when effected by starch. The decrease in the digestibility appears to be rather smaller, however.

Effect on Digestibility of Nitrogen-free Extract.—Thus far we have considered chiefly the effect of easily digestible carbhydrates on the digestibility of protein and fibre. In regard to the nitrogen-free extract and the fat of the coarse fodder, it may be said that the digestibility of these constituents is not essentially decreased by starch or sugar so long as the latter are completely digested.

Frequently, however, the starch or sugar not only diminishes the digestibility of the protein and fibre, but escapes digestion itself to a not inconsiderable extent, thus causing a double loss. We have here another indication of the necessity of observing a medium nutritive ratio in the fodder of farm animals.

Indeed, a too-wide nutritive ratio may cause more waste than a too-narrow one. In the former case the protein consumption is, as we learned in Part I., needlessly increased, but the nitrogen of this protein is excreted in the urine, and has its value in the manure. In the second case, a too-wide nutritive ratio also causes a waste of protein by decreasing its digestibility, but it also causes some of the starch to pass through the body without being put to any use, while as manure the latter is absolutely valueless, containing only elements of which the atmosphere offers an inexhaustible supply to plants.

Roots.—It will not often be the case in practice that pure starch or sugar is fed, but potatoes and roots, which are especially rich in carbhydrates or pectin substances, must exert a similar influence on the digestibility of coarse fodder. It is to be expected, however, that the resulting depression will be smaller than that caused by pure carbhydrates, since the above-named fodders contain, besides starch and sugar (or pectin), other substances, and especially more or less albuminoids.

The effect of roots and potatoes on the digestibility of a ration has been investigated chiefly at the Hohenheim Experiment Station, where a large number of experiments on sheep have been executed.*

In calculating the results of these experiments the potatoes and roots have been considered as wholly digestible, and any decrease in the digestibility of the ration is considered as affecting exclusively the remaining fodder. The grounds which justify this assumption are two: first, it is known that these feeding-stuffs are very completely if not wholly digested, and that large amounts of starch or sugar do decrease the digestibility of a ration; second, with our present knowledge this method of expressing the results is the most convenient for practical purposes. It should never be forgotten that investigations of this sort are of a practical and not a physiological nature. In feeding, it is not the digestibility of one feeding-stuff so much as that of the whole ration which is of importance, and hence that method of expressing the results of digestion experiments is best which attains this end by the simplest method consistent with accuracy. Probably roots are *not* wholly digestible, but at present it is not possible to calculate digestion coefficients for them as has been done for the other bye-fodders.

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* Landw. Jahrbücher, VIII., I. Supplement, p. 123. Compare also Wolff's "Ernährung Landw. Nutzthiere," pp. 158–175.

Calculated on this basis, these experiments yielded, in general, the same results as those on the feeding of starch and sugar, viz.: that the depression of the digestibility was greater, the larger the amount of the bye-fodder and the wider the nutritive ratio. The following table by Wolff, in which the results are grouped according to the propor-

Dry matter of bye-fodder in per cent. of coarse fodder.	Depression.—Per cent.					
	Protein.		Nitrogen-free extract.		Organic substance.	
	Potatoes.	Roots.	Potatoes.	Roots.	Potatoes.	Roots.
12 to 18........	7.3	4.0	5.3	2.2	4.4	3.0
22 to 35........	13.9	7.1	6.5	4.7	7.5	5.9
44 to 54........	27.8	11.9	14.7	6.8	17.1	9.3
64 to 95........	40.2	22.3	13.9	10.2	17.5	11.7

tion of bye-fodder, will serve to give an idea of the extent of the depression. The numbers denote the decrease in the digestibility of the protein, nitrogen-free extract, and total organic matter, under the influence respectively of roots and potatoes. The depression is calculated in percentages of the amounts of the several nutrients digested when the bye-fodder was withheld.

The decrease in the digestibility of the non-nitrogenous ingredients caused by any amount of roots or potatoes likely to be fed in practice is so small that we may neglect it, and consider only the effect on the protein.

From the above numbers, Wolff concludes that we can assume that, when the dry matter of the bye-fodder of ruminants amounts to $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{2}$, and finally equals that of the coarse fodder, the digestibility of the crude protein of the latter is decreased by about 7, 14, 28, and 40 per cent. if the bye-fodder consists of potatoes, and by about half as much if it consists of roots.

It is plain, however, that these numbers can be but approximations, since, in general, the decrease of the digestibility varies with the nutritive ratio of the whole ration. It seems probable that, in practice, the most satisfactory method would be to use these figures as a basis for compounding a ration, and then to compute the digestibility of the total crude protein by means of Stohmann's formula (p. 256). In cases of doubt, it is well to err in giving slightly too much rather than too little protein, not only for the sake of ensuring the digestion of the non-nitrogenous nutrients but to ensure also a sufficient supply of the important albuminoids to the animal.

For similar reasons it is well, when feeding large quantities of roots along with hay or straw, to add to the ration a small amount of some highly nitrogenous bye-fodder, like oil cake, in order to narrow the nutritive ratio and ensure as complete a digestion as possible, both of the nitrogenous and the non-nitrogenous nutrients.

As noted, all the above experiments were made on sheep, and their results are applicable, in the first place, to ruminants. A similar depression in the digestibility of the crude protein in the food of the hog is produced by starch, and presumably by roots, while the digestibility of the non-nitrogenous nutrients seems little or not at all affected.

Finally, it should be added that the digestibility of potatoes, when fed exclusively to hogs, has been the subject of investigation at the Experiment Stations of Proskau and Hohenheim. The results of these experiments are included in Table II. of the Appendix.

Effect of Fat.—Experiments on the effect of the addition of small amounts of fat or oil to a ration on the digestibility of the constituents of coarse fodder have hitherto given very variable and more or less discordant results.

There is little doubt that in high feeding, intended to cause a rapid production, the fat of the ration is of importance, and has considerable influence on the nutritive effect, but the weight of evidence goes to show that the *digestibility* of the various nutrients is not essentially altered by an addition of fat to the fodder.

Care must be taken, however, not to give ruminating animals too much fat, since it may easily cause a gradual loss of appetite and even serious disturbances of digestion. It is to be noted that such an injurious effect is much less noticeable when the fat forms an actual constituent of the fodder, as, *e. g.*, in oil cake, etc., than when pure fat is mixed with the fodder.

This is illustrated by some Hohenheim experiments on sheep. The fodder was tolerably rich in protein, and by the gradual addition of increasing quantities of palm-nut meal and flaxseed the amount of fat per day and head was increased finally to 75 and 100 grammes, while the quantity of the remaining nutrients was scarcely altered. The digestibility of the fodder was not affected at all, either favorably or unfavorably, and the health of the animal did not suffer.

EFFECT OF SALT.—That salt plays an important part in the nourishment of the animal organism, and is for the herbivora, even more than for the carnivora, an indispensable food, has been already explained. Upon the digestibility of the fodder, however, it seems to exert no considerable influence in any way. The result of direct experiments in Salzmünde, Hohenheim, Dresden, and Proskau, has been to show sometimes an apparent decrease, and sometimes an apparent increase, of digestibility as a result of the feeding of salt.

Generally, however, under wholly normal conditions, salt has shown itself without influence in this respect.

The greater palatability of a fodder, and the larger amount consequently eaten as a result of salting, is not to be confounded with its percentage digestibility, which, as we have seen (p. 259), is in general little affected by the quantity eaten, especially of coarse fodder.

Besides salt, other inorganic matters are sometimes fed, especially phosphate of lime. This is not the place to consider the necessity of such a procedure, nor its effects on the nutrition of the animal. Here it need only be said that, like salt, they appear to exert no effect on the digestibility of the organic nutrients.

CHAPTER II.

THE COARSE FODDERS.

In the preceding chapter, we have considered, in a general way, the digestibility, and incidentally some of the other properties, of the more common classes of feeding-stuffs. We now proceed, in this and the following chapters, to take up the chief members of these classes for a more detailed study. In this we shall regard the feeding-stuffs chiefly as sources of the various nutrients—that is, we shall look at them from a chemical standpoint, and make their composition the prominent point.

The greater or less adaptability of particular fodders to particular kinds of animals we shall leave entirely out of account, simply because it is as yet entirely a matter of practical observation and experience.

The subject of the cultivation of fodder plants, too, is outside the scope of this work, and will only be alluded to incidentally, in so far as the different methods of cultivation and manuring may influence the composition or digestibility of the resulting crop.

§ 1. Meadow Hay, Rowen, and Pasture Grass.

Variable Composition.—While the seeds of the same plant, and hence their bye-products, are generally quite constant in their chemical composition and nutritive value, it is characteristic of the stems and leaves, which constitute what we call coarse fodder or forage, that they vary very considerably in composition, according to the circumstances under which they grow, their state of maturity, etc. It is, therefore, of the highest importance to learn how these various factors affect the value of a fodder. In the following paragraphs we shall consider their influence on the composition of hay, premising that it is essentially the same on all coarse fodders.

Supply of Plant Food.—It is a well-established fact that the natural quality and the fertility of a soil have a very considerable influence on the chemical composition of the crop, especially of coarse fodder.

This influence is particularly noticeable on the nitrogenous constituents of the fodder. According to analyses made in Tharand, the hay from a manured meadow contained 12 per cent. of protein, that from an unmanured one only 9 per cent. Still greater differences often show themselves when dark green, "rank" plants are compared with pale yellowish-green ones of the same kind, occurring in the same field, and of the same age.

This was observed, *e. g.*, in investigations made in Möckern. Rank plants of oats, barley, wheat, and rye contained at the beginning of flowering 16.4 per cent. of protein in the dry matter, while weaker plants contained only 10.4 per cent.

It is not improbable that the low percentage of crude protein which seems to be characteristic of American, or at least of New England, hay, as compared with that raised in Germany and Austria (compare "Report Conn. Ag'l Expt. Station," 1879, pp. 79-83), is owing to its having been raised on poorer soils.

Some analyses made by Weiske & Wildt,* in Proskau, are of interest in this connection. The fodder grew on a heavy clay soil, and consisted, for the most part, of timothy (*Phleum pratense*), with a slight admixture of red clover.

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* Jahresber. Agr. Chem., XIII., III., 9.

One sample (I.) came from a part of the field which was in an ordinary state of fertility; the other (II.) was taken from spots where the excrement and urine of the grazing animals had caused an especially luxuriant growth. The two samples had the following composition in the water-free state:

	Protein. Per cent.	Crude fibre. Per cent.	Fat. Per cent.	Nitrogen-free extract. Per cent.	Ash. Per cent.
I.	11.0	22.5	4.2	56.3	6.0
II.	20.3	26.6	4.8	41.3	7.0

The differences are very considerable, especially in the amount of protein and nitrogen-free extract.

It is noticeable that the greatly increased percentage of protein in II. is accompanied by a not inconsiderable increase in the quantity of crude fibre, in consequence of which the digestibility of the protein is most probably diminished. According to practical experience, a very rank fodder, such as grows on heavily-manured land, and especially in wet and shady places or in wet seasons, is not especially nutritious, even though it contains much crude protein. This may be partly because the protein is less digestible and partly because the bulk and coarseness of the fodder render it unpalatable. Moreover, high manuring, especially with nitrogenous fertilizers, tends to increase the proportion of "non-protein," which is less valuable, in some respects at least, than true protein.

It would be very interesting to make systematic digestion experiments with the different qualities of fodder obtainable by different manuring of the same soil, in order to determine the actual practical value of high manuring for fodder crops. As yet this has not been done.

Method of Curing.—The method of curing almost universally adopted in this country is drying. Evidently, this alone cannot change the composition of the dry matter of the fodder, and we have seen that the digestibility is in no essential degree affected when the drying is carefully conducted.

On the other hand, it has been already stated that in the preparation and handling of hay, as commonly conducted, more or less loss of substance is unavoidable, and that this loss consists of the most nutritious parts of the plants. As a result, both the composition and digestibility of the hay suffer (compare p. 306).

Obviously, it is desirable to reduce this loss to the minimum. Hence all methods and appliances which diminish the amount of handling which the hay must receive, especially when it is nearly dry, tend to improve the quality of the product. So, too, it is desirable to dry the grass as little as is consistent with the object of curing, viz., to ensure the keeping of the fodder, since the dryer and more brittle it becomes, the greater is the loss by handling.

In the process of "ensilage," long practiced in Europe and lately introduced into this country, these losses are largely avoided, the fodder being placed in the silo while still green. On the other hand, the process of fermentation which the fodder undergoes causes losses in other ways. In this country ensilage has been chiefly recommended for maize, and we shall consider it more fully in that connection.

Damage by Rain.—In our hot and dry summers, in which hay can usually be sufficiently cured in a single day, hay is far less exposed to damage from rain than is the case in the moist climate of Germany and England. At the same time it is impossible to altogether avoid it, and it is therefore of interest to know its effects on the hay.

Both analysis and digestion experiments confirm the common observation that hay which has been wet is diminished in value. A loss of crude protein and nitrogen-free extract, and a relative increase in the crude fibre, are generally observed, combined with a decreased digestibility.

Stage of Growth.—As has been already pointed out (p. 33), plants while still young and rapidly growing contain relatively more protein and less fibre than more mature ones. Consequently, early-cut fodder must, other things being equal, be of better quality than late-cut. This is well illustrated by the following analyses, executed at Hohenheim,* of hay cut at three different times from the same meadow:

WATER-FREE SUBSTANCE.

Cut.	Protein. Per cent.	Crude fibre. Per cent.	Fat. Per cent.	Nitrogen-free extract. Per cent.	Ash. Per cent.
May 14, 1877.....	18.97	24.70	3.42	43.91	9.50
June 9, "	11.16	34.88	2.74	43.27	7.95
" 26, "	8.46	38.15	2 71	43.34	7.34

The table shows a decrease of crude protein and an increase of crude fibre, both of which impair the quality of the fodder.

Furthermore, we have seen (p. 263) that early-cut fodder, like that of May 14th, is much more digestible than that cut later, and the real value of a fodder is, of course, measured by the amount of digestible nutrients it contains. In the above case 100 pounds of each fodder contained the following amounts of digestible matters:

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* Landw. Jahrbücher, VIII., I. Supplement, 54.

Cut.	Digestible organic substance. Pounds.	Digestible protein. Pounds.	Digestible crude fibre. Pounds.	Digestible fat. Pounds.	Digestible nitrogen-free extract. Pounds.
May 14th.......	69.20	13.85	19.76	2.22	33 37
June 9th........	59.31	8.04	23.02	1.42	26.83
" 26th........	53.45	4.74	23.27	1.17	24.27

It will be seen that the total quantity of digestible matters and the amount of digestible protein, the most valuable of the nutrients, furnished by 100 pounds of the early-cut hay is considerably greater than that yielded by the same weight of that cut later. Many more examples of the same fact might be adduced were it needful.

Early or Late Cutting.—The question of early or late cutting is one that is frequently raised, and the considerations just adduced enable us to indicate, to some extent, its answer. Three elements enter into the problem, viz., the quality of the fodder, its quantity, and the amount of labor expended upon it.

As just illustrated, young plants are relatively richer in protein and poorer in crude fibre than old ones, and therefore more nutritious; so that if the only question were the quality of the fodder, the best results would be obtained by cutting as early as practicable.

But we have to consider not only the quality of the fodder but the quantity of it which we can obtain from a given area, and this complicates the question somewhat.

In the young plant protein is formed rapidly, but as it grows older the vital activities are directed more to the translocation of protein already present than to the production of new. This is especially the case after blossoming, when the protein before present in the stems and leaves is transferred to the seeds and there stored away. At the same time a continual formation of woody fibre goes on, so that a large proportion of the increase in weight of plants after a certain point is due to this substance, and although the absolute quantity of protein is not decreased, its percentage in the whole mass of the plant is. When crops are raised for fodder, the object generally is to produce the greatest possible amount of *digestible* nutrients per acre. If it were a question simply of producing the greatest number of pounds of nutrients, digestible or indigestible, per acre, if we were confined to one crop in a season, we should let that stand as long as possible, since we have no evidence that there is any *loss* of organic matter during ripening. But supposing, for the present, that only one crop is raised in a season, we have seen that the older plants become, the less digestible they are. For this reason, though we might get a greater quantity of nutrients per acre by letting a year's crop, *e. g.*, stand till fully ripe, we should probably lose more in digestibility than we gained in amount.

Furthermore, as we have just seen, while any crop is ripening a large part of the protein and starch passes from the leaves and stem to the seeds, leaving the former relatively poor and woody. Now, in the case of grass, the seeds are nearly worthless for fodder, since they are so small as to escape mastication, while whole seeds are seldom digested, being protected by their integuments from the action of the digestive fluids. Moreover, they are easily lost in curing, so that these two circumstances combined cause the loss of practically all the nutrients contained in the seeds. The grasses belong to the same order of plants as the grains, and hay made from fully ripe grass is essentially straw. No farmer would expect to obtain nutritious fodder from a field of ripe oats, if he neglected the seeds and collected only the leaves and stems of the plants; yet this is exactly what is done of necessity when grass is allowed to ripen before cutting. The straw is collected, while the seeds, which contain most of the valuable material, unavoidably escape.

If only one crop is to be obtained, probably the best time for cutting is usually when the plants are just beginning to blossom. At this time a larger crop is obtained than if cut earlier, while the digestibility is not seriously impaired. It is during the ripening of the seed that the most extensive changes in this respect go on. If a high nutritive value is desired rather than quantity, of course a still earlier harvest would be in place.

In the case of grass, it is a further advantage of seasonable cutting that a second crop may be obtained, and often by frequent successive cuttings a very considerable amount of highly nutritious fodder may be obtained. For example, the crop of a meadow in Hohenheim was obtained from one-half at a single cut, from the other in two. The following were the results:

	Percentage of protein.	Total protein. Pounds.	Total dry matter. Pounds.
One cut	16.3	434	2,662
Two cuts	24.4	668	3,274

These numbers speak most decidedly in favor of early cutting. Where the fodder was cut twice, not only was the quality far better, as shown by the percentage of protein, but the absolute quantity both of protein and of dry matter per acre was nearly one-half greater. When we take into account the greater digestibility of the young hay, the gain becomes still larger. Numerous similar experiments have been made with clover, and these will be mentioned in the next section. One made by Weiske, in Proskau,* on a mixture of grass and clover, may be described here. It is of especial interest because the digestibility of the fodder was determined by direct experiments on sheep.

A field was sown with a mixture of clover and grass seed, and divided into two equal portions.

In the time from April 24th to August 24th, the young vegetation on one half of the field was plucked by hand thirteen times, in imitation of the effects of pasturage, while the other half was mown twice.

The following table gives in pounds per Prussian *Morgen*, first, the total yield of the several nutrients, and second, the amounts of *digestible* nutrients obtained.

TOTAL YIELD.

	Dry substance. Lbs.	Protein. Lbs.	Crude fibre. Lbs.	Nitrogen-free extract, and fat. Lbs.
Plucked......... ...	2,122	575	355	1,002
Mown twice.........	3,392	485	899	1,797

DIGESTIBLE.

Plucked............	1,457	450	239	768
Mown twice.........	2,016	307	444	1,264

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* Wolff, "Ernährung Landw. Nutzthiere," p. 108.

The composition of the water-free substance of the two fodders was:

	Plucked.	Mown twice.
Protein	27.07	13.42
Crude fibre	16.74	27.14
Fat	5.09	3.69
Nitrogen-free extract	42.09	49.69
Ash	9.01	6.06

In this experiment the frequent cutting gave a very rich fodder, and, at the same time, yielded absolutely more digestible protein and about 40 per cent. less non-nitrogenous digestible matters per acre.

All these results indicate that the richest fodder and the largest yield of digestible matters per acre may be obtained by cutting two or more crops of comparatively young grass in a season, rather than one crop of over-ripe vegetation.

In practice, however, the fertility of the soil, the length of the season, the cost of labor, etc., have to be considered, and in the nature of the case, no general rules can be given. The chief advantage of early cutting lies in the better quality of the resulting fodder. Late cutting, if not too late, yields a greater number of pounds of digestible non-nitrogenous nutrients per acre than early cutting, but the resulting fodder is deficient in albuminoids and is usually not suitable for exclusive feeding. Obviously, however, circumstances may be such as to render it more economical to supplement the poor hay obtained by late cutting by nitrogenous bye-fodders than to be at the expense of cutting two or more crops, while under other conditions the opposite course may be advisable. Such being the case, each farmer must strike the balance for himself between quality, quantity, and cost.

Rowen.—It is evident that the value of rowen must be very variable, according to the soil, the time at which the first crop was taken off, etc. It is generally likely to be cut at a comparatively early period of growth, and then, if properly cured, constitutes an excellent fodder. It is, however, more liable to injury from wet than the coarser hay of the first crop, and may easily suffer considerable damage in this way.

Pasture Grass.—The high nutritive value of the young grass of good pastures is evident from the foregoing paragraphs (compare the analysis on p. 292). The question of the relative advantages of pasturage or stall-feeding, however, is a purely economical one, and as such is entirely outside the scope of this work.

Proportion of Non-Protein in Hay.—Recent investigations, especially those of Kellner, already alluded to (p. 37), have shown that a comparatively large proportion of the nitrogenous matters of hay and other coarse fodders is not albuminoids, but belongs to some of the classes of non-albuminoid nitrogenous matters enumerated on page 34, and which we have collectively designated as non-protein. In thirty-one samples of various kinds of coarse fodder, he found (*loc. cit.*, p. 245) the non-albuminoid nitrogen to range from 0.102 to 2.133 per cent. of the dry matter of the fodder, and from 7.5 to 38.5 per cent. of the total nitrogen. In meadow hay the range was 0.102 to 0.983 per cent. of the dry substance, and 7.5 to 34.8 per cent. of the total nitrogen. In nineteen samples of hay examined by the author,* the non-albuminoid nitrogen was found to be from 0.09 to 0.46 per cent. of the air-dry substance (14.3 per cent. of water), and from 8.93 to 24.36 per cent. of the total nitrogen, the average being, respectively, 0.21 and 16.70 per cent. According to Kellner's investigations, most of the non-albuminoid nitrogen exists in the form of amides.

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* Report Conn. Ag'l. Expt. Station, 1879, p. 112.

Although the amides, as we have seen, are easily digested and have some nutritive value, yet they cannot be considered equal to the albuminoids, and it is clear that the large amount of them which hay sometimes contains must diminish its value.

Non-protein in early-cut Hay.—The statements made on page 36 respecting the functions of amides in the plant would lead us to expect to find them chiefly in those plants or parts of plants where growth was going on, while in those which had reached their full development we should anticipate finding most or all of the amides reconverted into albuminoids, except in cases where, as in the beet, they act as a reserve of nitrogenous food. As a matter of fact, those investigations which have hitherto been made confirm, in the main, these anticipations.

Thus Kellner's results show that, in general, the proportion of non-protein is greatest in the hay from young plants, and decreases as the latter approach ripeness. An interesting difference was observed in this respect between the common grasses (*Gramineæ*) and the legumes; in the former the decrease in the amount of non-protein with approaching ripeness was very marked, while in the latter it was much less noticeable. The former are plants which, after flowering, cease to assimilate to any great extent, while the latter, along with the formation of flower and fruit, continue to grow and assimilate food, and thus offer the conditions for the formation of amide compounds.

The following table of a few of Kellner's results, giving the proportions of total and non-albuminoid nitrogen, will serve to illustrate these facts:

	Total nitrogen. Per cent.*	NON-ALBUMINOID NITROGEN.		Amide nitrogen. (Sachsse's method.) Per cent.*
		Per cent.*	Per cent. of total nitrogen.	
LUCERNE.				
1. Cut April 7, 1½ in. high..	6.922	2.133	30.5	.....
2. " " 12, 3½ in. high.	5.760	2.042	35.5	.....
3. 2d cut, without flower buds.	3.570	1.183	33.1	1.025
4. Before flowering, 18½ in. high................	2.474	0.721	29.1	0.613
5. In flower, 22½ in. high...	3.008	0.729	24.2	0.687
RED CLOVER.				
1. Cut March 27, 1½ in. high.	5.200	1.958	37.7	.....
2. " April 27, 2½ in. high.	3.974	0.975	24.5	.....
3. In full flower...........	2.244	.....	(16.5)	0.370
MEADOW HAY, 1877.				
1. Cut May 14.............	2.824	0.983	34.8	0.892
2. " June 9.............	1.787	0.285	16.0	0.239
3. " " 29...........	1.354	0.102	7.5	0.033

Kellner also shows (*loc. cit.*, p. 248) that hay which has been heavily manured, like that whose analysis is given on page 290, is usually rich in non-albuminoid nitrogen.

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* Per cent. of water-free substance.

Obviously, these results have an important bearing on the comparative value of early-cut as compared with late-cut hay. In all the experiments on this subject which are adduced in the foregoing paragraphs, the protein includes all the nitrogenous matters of the fodders. Could the proportion of non-protein have been taken into account, the results would, doubtless, have been somewhat modified; but, at the same time, it does not appear probable, from what we now know, that they would have been essentially different. In all Kellner's experiments, the amount of true protein, as well as of non-protein, was greatest in the earliest cut fodders, and we have seen (p. 265) that the true protein of early-cut hay appears to have a greater digestibility than that of late-cut.

Moreover, most of the non-protein was in the form of amides, which we have seen to have a certain nutritive value.

While, then, these recent results show that the comparative value of early-cut hay and green fodder may have been overestimated somewhat, they still show that its quality is superior to that of late-cut, other things being equal.

§ 2. The Legumes.

The legumes—including the various kinds of clover, lucerne, vetches, lupines, etc., as well as peas and beans—are characterized by the large proportion of protein contained both in the plant as a whole, and in the seeds. Owing to this and to the fact that they are plants which are much more independent of the supply of nitrogen in the soil, or at least in manures, than are the grasses and grains, they are of much importance in agriculture. As fodders, when properly cut and cured, they are very rich, but have the disadvantage of being rather bulky, and of being easily subject to deterioration by mechanical losses.

Clover and Clover Hay.—What has been said concerning the variable composition of meadow grass and hay applies with equal force to clover and to all coarse fodders.

As a general rule, clover is richer in nitrogenous matters than grass, and an admixture of clover with meadow hay usually improves the quality of the latter, while not imparting to it the bulkiness of pure clover hay.

As regards its digestibility, it may be said that, compared with meadow hay, its protein is about equally digestible, its crude fibre decidedly less digestible, doubtless owing to the lignin which it contains (p. 41), and its nitrogen-free extract and fat rather more digestible. As in meadow hay, however, the digestibility is largely influenced by the quality of the fodder, and this again by the same influences which affect that of all coarse fodders.

Period of Growth.—What has been shown to be true of meadow hay in this respect applies also to clover. The earlier it is cut the more concentrated and digestible a fodder does it yield, while, as it grows older, the crude fibre increases, and it becomes coarse and less easily digestible.

For example, analyses made in Hohenheim of clover cut at different times gave the following percentages of protein in the dry matter:

Cut May 1st	23.3	per cent.
“ June 13th	16.6	“
“ “ 23d	13.4	“
“ July 20th	11.4	“

In Möckern the following results were obtained for protein in the dry substance:

Cut May 20th	19.6 per cent.
" June 7th	16.3 "
" " 20th	13.2 "

That with the decrease of protein and increase of crude fibre the digestibility of the former as well as of the total organic matter decreases has been already shown (compare p. 263).

Best Time for Cutting.—In regard to the best time for cutting clover, the considerations advanced in the preceding section concerning grass are applicable, as shown by numerous experiments. That clover, when cut young, is of better quality has been sufficiently shown already. In regard to the advantages of early and frequent cutting, the experiments, while they speak decidedly in favor of it, do not all give such striking results as those on grass. One such experiment on a mixture of grass and clover has already been adduced (p. 296). Another, also made in Proskau, gave the following results in pounds per Prussian *Morgen:*

	Dry matter. Lbs.	Protein. Lbs.
Three cuttings	3,570	750
Two cuttings	3,392	485

Here, again, we have a decided gain by the more frequent cutting, even taking no account of the better quality and greater digestibility of the fodder.

Clover and similar plants, to be sure, do not endure too frequent cutting as well as the grasses; if cut often, they frequently yield only a relatively small amount of fodder, but one of excellent quality.

In Tharand, one part of a clover field was cut six times between May 29th and August 24th, in imitation of the effects of pasturage. The resulting fodder and one obtained from another portion of the same field in two cuttings (July 7th and August 24th), made when the clover was in full bloom, yielded the following amounts of dry matter, protein, and crude fibre, in pounds, per Saxon *Morgen:*

	Dry matter. Lbs.	Protein.	Crude fibre.
Six cuttings..	2,924	615 lbs. =21.0 per cent.	637 lbs. = 21.7 per ct.
Two cuttings.	5,811	762 lbs. =13.1 per cent.	1,954 lbs. = 33.6 per ct.

Although nearly twice as great an amount of dry matter was obtained from the older clover, the advantage thus gained was nearly equalized by the far better quality of the younger, especially if we judge it by its content of protein. The percentage composition shows that the absolute quantity of *digestible* protein in the young clover was as great, and perhaps greater, than that in the old.

Losses in Curing.—What has already been said of the losses incident to the curing of hay in the ordinary manner applies with still greater force to clover. The stems of clover are comparatively coarse and thick, while the leaves, on the contrary, are thin and tender. Consequently, an amount of drying sufficient to properly cure the stalks is likely to render the leaves so dry that they will easily crumble and be lost in handling. Still further losses of the same sort are liable to occur in the mow in the course of a winter.

These losses are all the more serious because the leaves of clover are especially rich in protein, and this protein is probably far more digestible than that of the stems. In one observation the dry matter of the leaves was found to contain 22.3 per cent. of protein and that of the stems only 12 per cent., while of the total quantity of protein more than half was contained in the leaves. In other cases still greater differences between stems and leaves in this respect have been found.

All these considerations show the importance of avoiding these mechanical losses, so far as possible, by rapid curing, carried no further than is necessary, and an avoidance of much handling.

Effect of Wetting.—Clover is still more liable to suffer loss by rain than meadow hay, since from 25 to 40 per cent. of its dry matter is removable by extraction with cold water.

The loss consists largely of soluble portions of the nitrogen-free extract, and to a less degree of protein and ash, while the crude fibre is naturally but little affected. As a consequence, the residue contains much more fibre and much less extract in 100 parts, while the percentage of protein is usually little changed.

An extreme example of the deterioration of clover consequent on exposure to rain is afforded by the two following analyses made at Möckern.

The two samples grew in the same field, and were cut at the same time—at the beginning of flowering—but No. 1 was cured quickly without any essential loss, while No. 2 was exposed for fourteen days to almost daily heavy showers. The latter, when it was finally dried, appeared of tolerable quality, and could still be used as fodder, but a chemical examination showed that it had lost by extraction and fermentation 27.4 per cent. of the original dry matter, viz., 3.8 per cent. of protein, 20.6 per cent. of nitrogen-free extract, and 3 per cent. of ash. The percentage composition of the two samples of hay in the air-dry state (containing 16 per cent. of water) was as follows:

	No. 1.	No. 2.
Water	16.0	16.0
Protein	14.6	15.8
Crude fibre	25.3	37.4
Nitrogen-free extract and fat	36.1	23.4
Ash	8.0	7.5

It appears at first sight that No. 2, instead of having deteriorated, was rather improved in quality, since it contains 1.2 per cent. more crude protein than No. 1.

The increase is, however, only apparent, and is due to the fact that relatively more non-nitrogenous than nitrogenous nutrients are removed from clover by water; so that there may be a loss of protein and, at the same time, an increase of its percentage quantity in the residual fodder.

The protein remaining in the hay, however, must be the less digestible portions, and the amount of *digestible* protein would doubtless be greater in the good hay.

The great relative increase in the crude fibre deserves notice. It is, of course, due to the loss of the more soluble ingredients, and must tend to decrease still further the digestibility and value of the hay. These facts explain why, in practice, clover hay is sometimes met with which, although it contains considerable protein, is of the poorest quality, because it contains at the same time much crude fibre and little extract and is very coarse and indigestible.

LUCERNE.—This important fodder plant is in general even richer in protein than red clover, but is inclined to a more rapid formation of woody fibre after the flowers appear. Wagner* found the water-free substance of two samples cut respectively May 31st and June 30th to have the following composition:

	May 31st.	June 30th.
Protein	21.19	16.27
Fat	3.04	2.36
Nitrogen-free extract	36.74	37.30
Crude fibre	29.90	35.94
Ash	9.13	8.13
	100 00	100.00

Evidently lucerne demands early cutting, even more than clover, in order to yield a highly nutritious fodder.

Digestibility.—Most of the digestion experiments on lucerne hitherto executed have been made on material of exceptionally good quality, and much superior to what would be obtained in practice by the ordinary methods of curing.

Consequently, the digestion coefficients given in the Appendix are probably higher than would be ordinarily observed. In some recent experiments by Kellner† the digestibility of ordinary lucerne hay as cured in the field (No. 1) was compared with that of hay from the same piece of ground, dried under cover and without loss (No.

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* Jahresber. Agr. Chem., XVI., 25.

† Landw. Versuchs-Stationen, XXI., 425.

2). The composition and digestibility of the water-free substance of the two samples were as follows:

COMPOSITION.

	Protein. Per cent.	Crude fibre. Per cent.	Nitrogen-free extract and fat. Per cent.	Ash. Per cent.
No. 1	14.94	33.90	44.22	6.94
No. 2.	17.00	31.81	43.80	7.39

DIGESTIBILITY.

No. 1	67	45	62	23
No. 2	71	48	66	29

One thousand pounds of the green plants yielded the following amounts of digestible matters:

	No. 1. Lbs.	No. 2. Lbs.		No. 1. Lbs.	No. 2. Lbs.
Dry substance	140.16	162.84	Crude fibre	39.52	42.48
Organic matter	135.92	156.48	N. fr. ext. and fat	70.52	80.76
Protein	25.64	33.68	Ash	4.08	5.9

These results furnish a fresh illustration of the influence of the composition of a fodder on its digestibility, while the second table shows, in a striking manner, the very considerable losses incident to field curing.

As compared with clover of the same quality, we may assume, with comparative certainty, that the crude protein of lucerne is at least equally digestible. On the other hand, the crude fibre of lucerne is decidedly less digestible than that of clover, the nitrogen-free extract of the two fodders is about equally digestible, and the fat of lucerne, like that of meadow hay, seems to be difficult of digestion.

The large proportion of digestible protein which it contains renders lucerne both absolutely and relatively a very nitrogenous feeding-stuff. If fed exclusively, especially as green fodder, it supplies an excess of protein, and hence causes a waste of this valuable nutrient. It should therefore, in most cases, be used in connection with some feeding-stuff poor in protein, such as roots or straw, to realize the best effect.

VETCHES.—The coefficients given in the Appendix for vetches, are the results of six digestion experiments made in Hohenheim on sheep. The fodder was of excellent quality, cut at the very beginning of flowering, and cured in favorable weather; it is therefore not surprising that the digestion coefficients were nearly the same as those of the best clover hay, and for protein even higher.

Like lucerne, the vetch is inclined to a rapid formation of woody fibre after flowering, and deteriorates in quality. In Waldau the following percentages of protein and crude fibre were found in the water-free substance:

	Protein. Per cent.	Crude fibre. Per cent.
Cut May 23d	25.4	20.8
" July 12th................	13.8	39.8

In the state in which vetches are generally used for fodder, however, they may safely be considered to have a higher percentage of protein than clover.

LUPINES.—The yellow lupine yields, when cut just at the end of flowering, the most highly nitrogenous of all coarse fodders.

Experiments by Heidepriem * on lupine hay cut just as the pods were beginning to form, perhaps somewhat earlier than is customary in practice, showed that it contained the enormous quantity of 27.8 per cent. of protein in the dry matter.

The digestibility of the protein by sheep was found to be 74, that is, almost the same as in vetches and lucerne. This seems to indicate that at about 80 per cent. we have reached the maximum to which the digestibility of the protein of coarse fodder can rise, since with about the same percentage of crude fibre the quantity of protein varies in the three fodders just named from about 19.2 per cent. to 27.8 per cent., without producing any considerable increase of its digestibility.

A striking fact is the high digestion coefficient found for crude fibre (74), while in vetches and lucerne, both of similar composition, it was much lower, viz., about 54 and 38 respectively.

If this observation be trustworthy, lupine hay forms an exception to the general rule that the nitrogen-free extract is a measure of the total digestible non-nitrogenous matter; the relation in this case was found to be 100 : 124, *i. e.*, for 100 parts of nitrogen-free extract, 124 parts of extract and crude fibre together were digested.

Alkaloids of Lupines.—As is well known, lupine hay and green lupines, as well as the seeds of this plant, must be used almost entirely for sheep fodder, since other domestic animals eat them only unwillingly on account of their bitter taste, which is due to the alkaloids which they contain (compare p. 35). The large amount of protein in the lupine, however, renders it a valuable fodder, especially since it thrives best on a light, sandy soil and can contribute essentially to the improvement of the latter; but it must be fed even to sheep with caution, and only in combination with other feeding-stuffs less rich in protein.

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* Jahresber. Agr. Chem., 16, II., 118.

Poisonous Effects.—At various times poisonous effects have been observed to result from the feeding of lupine hay to sheep. These effects have frequently been ascribed to the alkaloids which it contains. In some years and in some places they have been very disastrous, while at other times or in other places no such results have been observed. More recent investigations indicate that the amount of alkaloids present in the hay is too small to produce any evil results, and that the cause of the poisonous effects is to be sought in fungi which attack the plants under certain, as yet unknown, conditions.

OTHER LEGUMES.—Besides the plants above described, there are a number of others which serve, to a greater or less extent, as fodder, either alone or in combination with other feeding-stuffs.

Numerous analyses of these plants have been made, but only exceptionally have they been the subject of exact digestion experiments, and hence their digestibility and value as fodder can be only approximately estimated by comparison with similar feeding-stuffs of analogous composition.

The so-called Swedish clover (*Trifolium hybridum*) is similar in quality to red clover, except that it is generally more tender and richer in nitrogen and can be fed to advantage in a more advanced stage of development. This is true in a still higher degree of white clover (*T. repens*), which, however, is generally cultivated only for pasturage in conjunction with other clovers and grasses.

The Medick (*Medicago lupulina*), frequently but incorrectly called yellow clover, must also be considered an excellent fodder, so far as mechanical state and chemical composition go, while the incarnate clover (*Trifolium incarnatum*) easily becomes woody, and has less nutritive value.

Another forage plant which is stated by some authors to have been lately brought before the public in Germany under various high-sounding names, is the sweet clover (*Melilotus alba*), also called "Bokhara clover" and "Stone clover." It does not appear, however, to be of any great importance, except possibly in dry, stony soils. It appears imposing on account of its height, but the proportion of leaves to stem is small, and the coarse stems rapidly become very woody, necessitating an early harvest.

The ethereal oil (cumarin) peculiar to the plant, too, though agreeable to cattle in very small quantities, renders the fodder unpalatable, if present in more than a trace. On this account, sweet clover should never be fed exclusively. When it forms a third, or perhaps, in case of sheep, a half of the whole ration of coarse fodder, the animals eat it freely, and it may be reckoned a fair fodder for sheep, horses, and oxen. It would probably not be suitable for milk cows, as the cumarin would be likely to impart a flavor to the milk.

Many authorities place a high value on the kidney-vetch (*Anthyllis vulneraria*), especially for light, sandy soils, where clover does not flourish. It is somewhat poorer in protein than the foregoing plants, but also contains less crude fibre, and is not inclined to become woody so rapidly.

Among its advantages are reckoned the facts that it is suited for a light, dry soil; yields a comparatively large quantity of nutrients even in dry years, when most crops are "burned up;" that the fodder made from it is very wholesome; that it resists frosts well; and that in the fall it may be pastured without injury to the next year's crop. It is eaten willingly by sheep and cattle, either green or as hay, and horses soon become accustomed to it.

The esparsette or sainfoin (*Onobrychis sativa*) seems, according to our present knowledge, to at least equal red clover in its percentage of protein, and to retain its palatability and digestibility to a somewhat later stage of growth.

Another plant cultivated on sandy soils—the seradella (*Ornithopus sativus*)—yields an especially fine, palatable, and easily-digestible fodder, which has the advantage over other forage plants that it retains its full value to the end of the flowering period.

It gives comparatively small crops, however, and in curing, the leaves, *i. e.*, the most valuable part, are easily lost. These last two crops, which seem to be but little cultivated in this country, are ranked by some authorities as of equal value with clover, and as even superior to it in a dietetic point of view, since they are not "heating." Like the kidney-vetch just spoken of, they withstand drought much better than clover, and it is claimed that a new variety of esparsette has been produced which yields larger crops.

This is not the place for a description of the plants or of their cultivation, but it would certainly be of interest to experiment on their cultivation in this country.

NON-PROTEIN IN THE LEGUMES.—On page 299 attention has already been called to the fact that the proportion of non-protein in the hay from leguminous plants is generally large, and does not decrease very markedly as the plants approach maturity.

Kellner's analyses are as yet the only ones that have been made. As the average of all his results, the non-protein amounted to 28.42 per cent. of the total nitrogenous matters, the variation being from 16.5 to 35.5 per cent.

§ 3. HUNGARIAN GRASS.

Composition.—Hungarian grass, or millet, has long been cultivated as a fodder plant in Southern Europe, where at least three species of it are distinguished. It is stated to withstand drought well, and to yield its largest crops in dry, hot seasons. It is a rapid grower, occupying the ground but about three months.

Only four analyses of millet grown in this country are reported.* The average of these analyses gives it about the composition of fair meadow hay. Two of these analyses, however, were made on somewhat immature samples, which were consequently richer in protein. The average of the other two samples is:

Water	16.70	per cent.
Ash	5.82	"
Protein	5.91	"
Crude fibre	28.06	"
Nitrogen-free extract	42.15	"
Fat	1.36	"
	100.00	

A fodder of this sort has about the same composition as the poorer grades of meadow hay. It is deficient in protein and rich in non-nitrogenous nutrients, and hence must be supplemented by some nitrogenous bye-fodder such as oil cake, in order to form a suitable ration for productive purposes.

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* Report Conn. Ag'l Expt. Station, 1879, p. 150

But one examination of millet for non-protein has been made.* In this case nearly 40 per cent. of the nitrogen was found to be contained in non-albuminoid compounds.

Digestibility.—No determinations of the digestibility of millet have been made. For the present, until such determinations have been made, we may assume it to have about the digestibility of hay of similar composition.

§ 4. Maize Fodder and Stover.

Composition.—By maize fodder we understand maize which is grown exclusively for the sake of its stalks and leaves, is cut comparatively early, and is either used for soiling or cured for winter fodder. By the term stover we designate the stalks and leaves of ripe maize from which the ears have been removed. The two are the same plant in different periods of growth, and it is evident from what we have already learned of the composition of plants in different stages of development, that maize fodder must vary greatly in composition according to the time at which it is cut, while stover will be found very much poorer in protein and richer in crude fibre and carbhydrates generally.

Green maize is a very watery fodder, containing from 80 to over 90 per cent. of water, but when cut early its dry matter is quite rich in protein. It is a very palatable fodder and well suited for milk cows, but is too watery for exclusive use.

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* Report Conn. Ag'l Expt. Station, 1879, p. 112.

That which is cut later, and especially that which is commonly cured for winter fodder, is usually rich in carbhydrates but poor in albuminoids, having a nutritive ratio of 1:9 to 12, or even wider. On this account it cannot be used exclusively, but must be supplemented by more nitrogenous feeding-stuffs; but when its proper function is recognized, viz., to furnish chiefly non-nitrogenous nutrients, and its deficiency of protein is made up by other ingredients of the ration, it forms a valuable feeding-stuff, which experience has shown to be well adapted to cattle. The necessity for the use of nitrogenous bye-fodders is, of course, still greater in the case of stover, which is estimated by Wolff to have about the same nutritive value as rye straw.

Digestibility.—On the digestibility of maize fodder we have but a single experiment, by Moser,* on a very good quality of maize fodder, which showed a high digestibility of all the nutrients, particularly crude fibre and fat.

From the results of one such experiment, however, no general conclusions regarding the digestibility of a fodder can be drawn.

Ensilage.—Within a short time the process of "ensilage" has been recommended to our farmers as a most advantageous method of preserving maize fodder in particular, and a few practical trials of it have given favorable results. While some extravagant claims have been made for it, it doubtless possesses certain advantages over field curing as well as certain disadvantages peculiar to itself.

The process consists essentially in storing the finely cut green fodder in suitable receptacles, in which it is closely packed, and which are so arranged as to exclude the air as completely as possible. For a more detailed description of the method, the reader is referred to the recently translated work on this subject by Goffart. With unessential modifications it has long been in use in Germany, the product being known as "sour maize" or "sour hay," while if the fodder be partly dried before being stored, it yields "brown hay."

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* Landw. Versuchs-Stationen, VIII., 93.

Advantages of Ensilage.—The chief advantages of ensilage as a method of preserving fodder are, that it is independent of the weather, a great advantage in some localities; that the fodder is handled when green, and that therefore no loss of the more tender and nutritious parts need be feared; that the resulting fodder is soft and easily masticated, and that the fermentation which takes place in it renders it, perhaps, more palatable to the animals.

These are not unimportant advantages, and in many cases may be sufficient to cause the adoption of the method. On the other hand, ensilage, of itself, adds nothing to the value of the fodder submitted to it, but rather diminishes it.

Chemical Changes in Ensilage.—In the silo a sort of fermentation is carried on at the expense of the extractive matters of the fodder, resulting in the formation of various organic acids and volatile bodies, and naturally diminishing the quantity of nitrogen-free extract, and thereby increasing the percentage of all the other ingredients.

This is illustrated by the following analyses of fresh maize and ensilage by Grandeau.* The two contained respectively 86.20 per cent. and 81.28 per cent. of water. The dry matter had the following composition:

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* Jour. d'Agric. prat., 1875, pp. 77 and 126.

	Fresh. Per cent.	Ensilage. Per cent.
Protein	6.52	6.62
Fat	1.30	1.92
Nitrogen-free extract	58.71	53.21
Crude fibre	26.59	26.23
Ash	6.88	12.02
	100.00	100.00

Some investigations by Weiske* on the ensilage of esparsette, in which the total amount of loss by fermentation was determined, show the nature of the alterations which the fodder undergoes still more clearly.

The composition of the dry matter of the fresh esparsette, as it was applied to the preparation of "brown hay" and "sour hay," and that of the dry matter of the two latter, was as follows:

	Protein. Per cent.	Fat. Per cent.	Crude fibre. Per cent.	Nitrogen-free extract. Per cent.	Ash. Per cent.
Fresh	18.56	2.89	33.93	38.60	6.02
Brown hay	20.69	4.87	32.38	35.06	7.00
Sour hay	20.44	6.02	35.18	30.88	7.48

As before, the fermented fodder is poorer in nitrogen-free extract and richer in other ingredients than the original materials. The loss of dry matter during fermentation was, in the case of the brown hay, 18.5 per cent., and in that of the sour hay, 24.0 per cent. Consequently 100 pounds of the dry matter of the unfermented fodder yielded the following quantities of nutrients in the three cases:

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* Jour. f. Landw., 1877, p. 170.

	Dry matter.	Protein.	Fat.	Crude fibre.	Nitrogen-free extract.	Ash.
Fresh (pounds).	100.0	18.56	2.89	33.93	38.60	6.02
Brown hay "	81.5	16.86	3.97	26.39	28.57	5.72
Loss (pounds).	18.5	1.70	+1.08	7.54	10.13	0.30
Loss (per cent.)	18.5	9.2	+37.4	22.2	26.3	5.0
Fresh (pounds).	100	18.56	2.89	33.93	38.60	6.02
Sour hay "	76	15.53	4.57	26.74	23.47	5.69
Loss (pounds).	24	3.03	+1.68	7.19	15.13	0.33
Loss (per cent.)	24	16.3	+58.1	21.2	39.2	5.5

These results render it evident that the preparation of brown hay, and still more that of sour hay or ensilage, involves a much greater loss of substance than is ordinarily to be feared in drying in the field. It is possible that the losses would be smaller with maize than with a highly nitrogenous fodder like clover or esparsette; but they are, doubtless, considerable. The apparent increase in the fat during fermentation appears to be due to the formation of lactic acid and other substances soluble in ether.

A certain advantage may perhaps be gained by ensilage in so far as the resulting fodder contains a larger proportion of protein, and therefore does not require so large an addition of bye-fodder. Corn being a comparatively cheap crop, the losses of material during the fermentation might be compensated by the improved quality of the residue.

It does not appear from Grandeau's analyses, however, that there is any very marked difference in this respect between fresh maize and ensilage. If this is generally the case, then fermented corn fodder has all the advantages of the fresh fodder, and no others, except perhaps as regards palatability, and ensilage is to be looked upon simply as *a* method of preserving corn fodder, and the question of its adoption is a purely economical one.

Effect on Digestibility.—No comparative experiments on the digestibility of ensilage have been made, but a few experiments in which small amounts of fodder were fermented (compare page 266) showed rather a decrease than an increase of digestibility. In Weiske's experiments the digestibility of both the brown and sour hay was found to be quite low. Weiske also found that the brown hay of lucerne had about the same digestibility as that dried in the field. It is not, therefore, to be anticipated that ensilage will be found to materially affect the digestibility of fodder.

Quality of the Fodder.—The value of fodder preserved by ensilage must evidently depend on the quality of the original material. The loss of non-nitrogenous matters which it suffers narrows the nutritive ratio somewhat, and renders it more valuable, pound for pound, than the green fodder. With this exception, the remarks already made concerning the quality and value of maize, as well as of other fodders, are applicable here. It is especially important to recollect that the composition of the ensilage, and its nutritive effect, must, of necessity, be just as variable as those of the fodder from which it is prepared.

The few analyses of ensilage which we possess show that, like corn fodder, it is rich in non-nitrogenous nutrients and poor in protein, requiring the addition of a bye-fodder rich in protein in order to produce the best results.

In conclusion, it may be added that in some cases injurious effects have been observed to result from too great acidity of the fermented fodder—a fault easily remedied by the addition of a little pulverized chalk.

§ 5. Tops of Root Crops.

Composition.—The leaves of the various root crops are very watery, but their dry matter is usually rich in nitrogenous matters, and contains but a small percentage of crude fibre. On the other hand, much of their nitrogen appears to be in the form of non-protein, and the leaves of mangolds and sugar beets in particular possess strong purgative properties, owing to the large proportion of salts and of organic acids which they contain. Consequently they must be fed with caution. German authorities recommend that they be treated by ensilage, and used in small quantities as an addition to winter fodder. Carrot and turnip tops possess the injurious property just named to a less degree.

Digestibility.—Experiments by Wildt* on the digestibility of fermented beet leaves, when fed with barley straw to sheep, showed that they had a fair degree of digestibility—57 per cent. of the total organic matter and 65 per cent. of the protein being digested.

Potato tops were found to be much less digestible. The latter, however, can hardly be accounted a feeding-stuff;

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* Landw. Jahrbücher, VII., 133.

they are comparatively poor in nutritive matters, and are coarse and unpalatable.

Leaves.—The leaves of deciduous trees have sometimes been used as fodder, the young shoots being cut off while the leaves were still green, and allowed to dry. The leaves contain a medium amount of protein, a small percentage of crude fibre, and considerable fatty matter and wax. In the experiments by Wildt just mentioned, poplar leaves were found to be fairly digestible. They are fed only to sheep, and are believed to exert an excellent dietetic effect when given in small quantities.

§ 6. STRAW OF THE CEREALS.

Straw a Valuable Fodder.—Straw is a feeding-stuff frequently regarded as of little value, and yet good straw is most decidedly better than poor hay. Indeed, hay and straw are practically almost the same crop, cut at different stages of growth. The grasses and the cereals both belong to the same natural order (*Gramineæ*), but while the former are (or should be) cut while still green, for the sake of their stems and leaves, the latter are grown primarily for their seeds, and are therefore harvested later, when much of their nutritive matters has passed into the seed. It may easily come to pass, then, that if, on the one hand, grass is cut very late or exposed to rain while curing, and if, on the other hand, grain is harvested early, the straw from the latter may exceed in value the hay of the former.

In any case, good straw is a feeding-stuff not to be despised. As the table in the Appendix shows, it is rich in non-nitrogenous matter, especially in crude fibre, and poor in protein, and hence is not suited alone to form a ration. Its value lies in its non-nitrogenous matters, of which it furnishes an abundant and cheap supply, and in combination with feeding-stuffs which can supply its deficiency in protein, it forms a valuable fodder. The old assumptions that the crude fibre of straw was indigestible, and that its digestibility, as a whole, was far less than that of other coarse fodders, have been shown to be erroneous; the experiments of Henneberg & Stohmann, since fully confirmed by numerous others, have shown indisputably that about half of the total nutrients of straw, including the crude fibre, are digestible, at least by ruminants, thus placing it on an equality with other coarse fodders as regards digestibility.

Straw is in general an entirely suitable fodder both for horses and cattle, similar in its dietetic action to hay. Straw which has suffered from diseases (rust, mildew, etc.), and is thereby rendered unfit to serve as fodder at all, is, of course, excluded in this statement.

Variations in Composition.—The composition and value of straw may vary considerably, depending, in the first place, on the kind of straw. Oat straw is usually the richest; then follows barley, which is valued for milk cows; next wheat, and last, rye, which is the poorest and least digestible of all. Summer straw is generally somewhat richer in protein and poorer in crude fibre than winter straw, and also more tender and digestible. The soil and manuring also influence the composition of straw in the same way as that of hay; a rich and well-manured soil yields a better fodder than a poor, unmanured one. The manner of sowing, too, has an influence on the quality; when thickly sown broadcast the plants shade each other, and the stalks remain more tender and succulent and less woody than the stalks of plants sown in drills and more exposed to light and air.

The time of harvest has a great influence on the nutritive qualities of straw, just as it does on those of hay. As in the latter so in the former, the earlier it is cut the richer in protein and the more nutritious it is.

In fields which have been seeded down to grain, the straw of the latter, in fruitful years, is often so intergrown with grass, clover, etc., as to essentially increase its value and enable it to entirely take the place of hay.

Digestibility.—Comparatively few determinations of the digestibility of straw have been made, oat straw being the one chiefly experimented on.

Henneberg & Stohmann found in exclusive straw feeding of oxen the coefficients 44 and 39 for protein; while Wolff, in experiments on sheep, obtained the much lower numbers, 33 and 14, with straw containing an equal percentage of protein. In the latter experiments, to be sure, the straw was raised in drills and was hard-stemmed, but the animals were allowed to select the tenderer parts, and only the straw actually consumed served as the basis of the calculation. The crude fibre of oat straw is quite as easily digestible as that of good hay, but the digestibility of the nitrogen-free extract and the fat is decidedly less.

On the digestibility of barley straw few experiments have yet been made.

In experiments by Wildt,* the digestion coefficient for protein was found strikingly low, viz., 17. The straw, evidently, was over ripe, and contained only 4.9 per cent. of protein in the dry substance. The digestibility of the nitrogen-free extract and the fibre was found to be 51 per cent. and 56 per cent. respectively. With a higher percentage of protein the digestibility of these nutrients in

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Landw. Jahrbücher, VII., 146.

barley straw would, doubtless, also be higher, and the latter would prove to be a valuable straw for feeding.

The relative digestibility of the constituents of winter straw is much the same as that of summer straw. The coefficients of the former, however, are usually somewhat lower, corresponding to the difference in composition.

This is the case only in a slight degree with the nitrogen-free extract and the fat, but is more noticeable in the case of protein and the crude fibre, as deduced from the accordant results of experiments made at Weende, Dahme, and Salzmünde on rye straw (in a single case only on wheat straw).

It has been already stated that the digestion coefficient for protein in feeding-stuffs having so little of this nutrient as the straw of the cereals, may easily be found too low on account of the admixture of biliary and other products in the excrements. At the same time, the straw used in most of these experiments was comparatively rich in protein, and at any rate the numbers thus obtained must be used until they can be replaced by more accurate ones.

Manner of Using.—Large quantities of straw in a ration are more suitable for ruminants than for the horse, since the former, on account of their large stomach, and the length and complexity of their digestive canal, are better able to utilize large masses of coarse fodder. For swine, straw is not well adapted.

Among ruminants, the sheep is better adapted than the ox to utilize straw. By means of its pointed mouth and flexible lips, it is easier for it to seek out the most valuable parts of the fodder, such as imperfect grains which have escaped threshing, short grass and other plants, and the ears and upper ends of the stems, while rejecting the coarser portions.

It is a very good practice to let all the straw which is to serve for litter be first put before sheep. In the finer and more tender parts which they seek out and consume, a much larger percentage of protein and a much narrower nutritive ratio is found than is shown by an analysis of the whole straw. According to Krocker's investigations * the nitrogen content of the stalk of barley and rye straw is to that of the leaves, leaf-sheaths, and ear-stalks as 1 to 1.9. That is, the latter contain nearly twice as much protein as the former, and when sheep have laid before them so much straw that they eat only these tender parts, they actually receive a fodder which differs little from hay in value.

Similar results were obtained by Arendt † in his investigation on the growth of the oat plant. In 100 grammes of dry matter from the various parts of the ripe plant the following quantities of nitrogen were found:

	Grms.
Three lower joints of the stem	0.79
" middle " "	1.17
" upper " "	1.56
" lower leaves	1.43
Two upper "	1.74
Ears	3.04

§ 7. Straw of the Legumes.

Composition and Digestibility.—Much of what has been said of the straw of the cereals is true of that of the leguminous plants, but the latter differs very considerably in composition from the former, just as clover hay does from meadow hay. The straw of the cereals is poor in protein and rich in non-nitrogenous matter; that of the legumes, on the contrary, is relatively richer in protein and has a narrower nutritive ratio, and hence is more nutritious and more digestible.

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* Annalen der Landwirthschaft, 1861, XII., 415.

† Compare "How Crops Grow," pp. 204–219.

The digestion coefficients for bean straw given in the Appendix are deduced from only a few experiments made in Weende, in which this feeding-stuff was fed to oxen. In this substance, as in clover hay, the crude fibre is less digestible and the nitrogen-free extract more digestible than in the straw of the cereals. The coefficients for pea straw are from a few experiments made in Hohenheim, in which only the more tender parts of the straw were eaten by sheep. The portion actually eaten had the composition of tolerably good clover hay (14.0 per cent. of protein, 31.9 per cent. of crude fibre), and the digestibility was correspondingly high.

In general, in the hay and straw of the legumes the crude fibre is less digestible and the nitrogen-free extract, on the contrary, more digestible than in the hay and straw of the gramineæ. The crude fibre of lupine hay forms a striking exception to this, and that of lupine straw (*i. e.*, the stalks and leaves remaining when the plant is cultivated for the seed) seems to show the same behavior. In both feeding-stuffs the whole quantity of non-nitrogenous matter digested exceeds considerably the amount of nitrogen-free extract found by analysis (see p. 310).

§ 8. CHAFF, PODS, AND MAIZE COB.

Chaff, etc.—Wheat chaff generally contains more protein than the straw. The chaff of barley and oats, on the contrary, is generally poorer in protein than the straw of the same plants. In the pods of the legumes we usually find at least as much protein as in their straw.

All kinds of chaff are, as a rule, poorer in crude fibre than the straw, and it is hence to be assumed that the digestibility of the remaining ingredients is correspondingly higher; but direct experiments on this point are still lacking. The mechanical condition of these feeding-stuffs causes them, when fed in proper quantity, to be more agreeable and palatable to cattle than whole or cut straw.

Maize Cob.—The question of the nutritive value of maize cob is one which has long been under discussion by practical farmers, but to which no decisive answer can yet be given. The evidence of chemical analysis goes to show that, like straw and similar fodders, its chief value is as a source of carbhydrates. The average of nine analyses of American maize cob * gives it the following composition:

	Air-dry.	Water-free.
Water	9.16	....
Ash	1.32	1.45
Protein	2.22	2.44
Crude fibre	32.04	35.31
Nitrogen-free extract	54.85	60.35
Fat	0.41	0.45
	100.00	100.00

No experiments on the digestibility of maize cob have yet been made, and hence it is impossible to pronounce definitely upon its nutritive value. Presumably, a considerable portion of it would prove to be digestible, particularly by ruminants, and from the results obtained regarding the digestibility of straw, etc., as well as from its composition, it is evident that the digested portion would be chiefly carbhydrates, with but little protein or fat.

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* Report Conn. Ag'l Expt. Station, 1879, p. 145.

The common method of using cobs as feed is to grind them with the grain, making "cob meal." Some recent practical trials* seem to indicate that the same nutritive effect may be produced by a less quantity of the kernel when the latter is fed along with cob as cob-meal, the difference being made up by the digestible matters of the cob. The latter, as has been said, probably consist chiefly of carbhydrates; their effect would be to widen the nutritive ratio of the ration, and thus to favor a more economical production. Unfortunately, these experiments did not include analyses of the fodder used, and hence their results, though interesting as indications of the digestibility of maize cob, are not suited for elaborate discussion here.

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* Report of Joint Committee of the Pomfret and Woodstock, Conn., Farmers' Clubs.—Connecticut Farmer, Nov. 15, 1879.

CHAPTER III.

CONCENTRATED FODDERS.

THIS name is given to those feeding-stuffs which, occurring largely in trade, contain in a given weight a relatively large quantity of digestible matters. The nitrogen-free extract consists for the most part of carbhydrates, particularly in the grains, and albuminoids and fat are frequently present in large proportions.

§ 1. THE GRAINS.

Value.—Of all the concentrated fodders the grains are perhaps the most important. They contain large quantities of nutrients and are a specific fodder for working animals. Practice seems to show that grain feeding for certain purposes is indispensable, and attempts to replace grain by other feeding-stuffs, even those in which chemical analysis shows an equal amount of nutritive matter, have either failed or met with but partial success.

It is especially suited for animals which have to perform severe work and for young animals; while for those which have reached maturity, and of which only a moderate amount of work is demanded, other feeding-stuffs may take its place, and for store animals, which perform little work, it is too expensive. Like most highly concentrated fodders, grain is somewhat difficult to digest, and too large quantities may easily cause disturbances of digestion, especially if not properly prepared.

Composition.—The grains contain the three groups of organic nutrients, viz., albuminoids, carbhydrates, and fat, in large quantities. The albuminoids of the grains have already been described to some extent (pp. 26–30). The carbhydrates consist largely of starch, the various grains containing in the air-dry state about 50 to 60 per cent. of this substance, accompanied by a small amount of gum and cellulose. The ether extract of the grains consists largely of true fat. We thus see that the organic matter of the grains consists chiefly of substances of undoubted nutritive value, and contains little waste matter; as a consequence their digestibility is high, and they contain a large amount of nutriment in a small bulk.

They are characterized by a medium nutritive ratio, the proportion of nitrogenous to non-nitrogenous nutrients being about 1 : 6–8 or in maize as wide as 1 : 10. This fact indicates their proper use. They are obviously not adapted to increase the proportion of protein in a ration containing too little of this nutrient: for this purpose we need a substance containing much protein and but a small amount of carbhydrates and fat. The grains find their application in cases where it is desirable to give a ration which, while having a medium nutritive ratio, shall contain much nutriment in a small bulk, and thus save digestive labor as explained on p. 228.

For example, the composition of the digestible portions of oats and of good clover hay does not differ greatly, but there is no question which is the more valuable fodder for a horse from which severe work is demanded.

Variations in Composition.—Grain, like coarse and green fodder, has a more or less variable composition, especially as regards protein, according to the conditions under which it is grown and harvested (soil, manuring, climate, weather, variety, degree of ripeness, etc.), although ripe grain of any particular kind is more constant in its composition than forage crops. Wheat and oats appear to be more variable than rye or barley; in the dry matter of American winter wheat from 9.23 per cent. to 16.54 per cent. of protein has been found by different observers. In spring wheat the range was 8.83 per cent. to 16.89 per cent. In some late experiments in Poppelsdorf, the percentage of protein in a variety of wheat already rich in this substance was increased from 16.3 in the unmanured wheat to 17.6 by an abundant manuring with superphosphates, to 21.4 by manuring with soluble nitrogen compounds (ammonia salts and nitrates), and to 22.4 by manuring with phosphates and nitrogen compounds; the protein of the straw was respectively 3.4 per cent., 3.7 per cent., and 5.2 per cent.

Other experimenters, indeed, have not been able to show such a decided effect of manuring on the composition of the cereals, and this effect may be, according to circumstances, either increased or diminished, or even entirely nullified by other factors, such as the quality of the soil, the weather, etc. Still, as a general rule, we are justified in expecting a more nitrogenous grain on a fruitful, highly manured soil than on its opposite or on one of only average quality.

Wheat.—The high value of wheat as food for man forbids its use as cattle food under ordinary circumstances. The average of all available analyses of American wheat is as follows: *

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* Report Conn. Ag'l. Expt. Station, 1879, p. 141.

	Air dry. Per cent.	Water free. Per cent.		Air dry. Per cent.	Water free. Per cent.
Water	10.72	....	Crude fibre	75 76	84 86
Ash	1.70	1.90	N. fr. extract		
Protein	11.82	13.24	Fat		

No determinations of the digestibility of wheat have yet been made.

Rye.—But one analysis of American rye is reported.* Wolff gives as the average of German analyses:

Water	14.3	per cent.
Ash	1.8	" "
Protein	11.0	" "
Crude fibre	3.5	" "
Nitrogen-free extract	67.4	" "
Fat	2.0	" "

Like wheat, rye is chiefly used as food for man. No determinations of its digestibility are reported.

Oats.—In oats, as in wheat, the percentage of protein is quite variable, and is largely determined by the thickness and weight of the hull, compared with that of the kernel. The latter is generally quite rich in nitrogen, and is distinguished by a comparatively high percentage of fat (5 to 7 per cent.). The percentage of protein in the whole grain is somewhat less than in wheat, the average being about 13 per cent. of the water-free substance in the latter, and perhaps 11 per cent. in the former.

The quality of a sample of oats is not always indicated by the weight of a given bulk, and it would doubtless often be advantageous in purchasing large quantities of so important a fodder, and one liable to vary so much, to have at least the amount of protein determined by chemical analysis. Such an analysis, of course, would not suffice to determine *accurately* either the nutritive or commercial value of the article; but, at the same time, it might be of material assistance in forming a practical estimate of the feeding value of a sample of oats or of any other grain.

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* Report Conn. Ag'l. Expt. Station, 1879, p. 141.

In a concentrated fodder like grain, the protein is the most important and most costly ingredient, as well as the one whose amount is subject to the greatest variations, and, other things being equal, the more protein the fodder contains the more valuable it is for the purposes to which it is applied. In conjunction with the weight, appearance, etc., of the grain, a determination of the protein would be an important factor in judging of its quality, and would have the advantage of rapid and comparatively easy execution.

Digestibility.—The digestibility of oats has been largely determined in experiments on sheep, though recently several experiments have been made on their digestibility by the horse. With the exception of three experiments, the results of which were evidently exceptional, these trials have shown a very uniform digestibility of this feeding-stuff, and therefore the average digestion coefficients may be considered comparatively trustworthy. The experiments on the horse* have shown that this animal is able to digest oats, as well as other concentrated fodders, quite as completely as sheep do.

Barley.—Barley is in general somewhat poorer in protein than the other common cereals, and the more so the more fully and uniformly the grains are developed, the percentage of this ingredient ranging, according to J. Kühn, from 6.2 to 18.3 per cent., and averaging about 11 per cent.

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* Landw. Versuchs-Stationen, XX., 125, and XXI., 19, and Landw. Jahrbücher, VIII., I. Supplement, p. 6.

But one experiment on the digestibility of barley by ruminants has been made, viz., by Schulze and Märcker, in Weende, on sheep. The results of this experiment agree very closely with those which have been obtained in several experiments on swine, and may therefore be assumed to be at least tolerably accurate. As is usually the case, the protein and fat were slightly better digested by the ruminants, while as regards the nitrogen-free extract the advantage was on the side of the swine.

Rice.—Rice is characterized by a low percentage of protein (about 7.5 per cent.), a very small percentage of fat, and a large proportion of starch. No experiments on its digestibility have been made.

Buckwheat.—Buckwheat, though belonging to an entirely different botanical family from the true grains (cereals), may be conveniently classed with them for our present purpose.

The percentage of protein in buckwheat is more than that in rice, but less than that in the other cereals, and about the same as in maize. It contains a considerable proportion of crude fibre, averaging 15 per cent., most of which is located in the hull or outer covering, and has rather less nitrogen-free extract than the cereals.

Maize or Indian Corn.—The cheapness, healthfulness, digestibility, and great fattening qualities of this feeding-stuff cause it to take a high rank among the grains. As regards chemical composition, the innumerable varieties which are known may be divided into two classes, sweet and common corn, having the following average composition:

AVERAGE COMPOSITION OF AMERICAN MAIZE.—WATER-FREE.

	SWEET.	COMMON.
	Average of eleven analyses.	Average of fifty-two analyses.
Ash	2.1	1.7
Protein	13.2	12.0
Fibre	2.3	1.9
Nitrogen-free extract	73.5	78.7
Fat	8.9	5.7
	100.0	100.0

"The greater richness of sweet corn in albuminoids and fat is very decided and indicates a higher nutritive value than that of common corn.

"The sweet corn contained on the average 8.6 per cent. of water, and the common contained 10.8 per cent., but the samples were unequally dried, and the analyses probably do not show the proportions of water that exist in corn in bulk as found in the crib or in market.

"The range of variation in the several ingredients is shown by the following statement of the lowest and highest percentages as found in these analyses:"

RANGE OF COMPOSITION OF AMERICAN MAIZE.

	Sweet.	Common.
Ash	1.6— 2.4	1.3— 2.0
Protein	10.2—15.9	8.7—14.4
Fibre	2.6— 3.0	0.3— 3.0
Nitrogen-free extract	69.6—79.5	75.2—82.2
Fat	5.8—10.2	4.4— 7.8

The analyses of American maize thus far made do not show any essential differences in composition between flint and dent corn, nor between eastern and western corn.

Common maize contains somewhat less protein and more non-nitrogenous matters than the cereals, and has a wider nutritive ratio. It is therefore not as valuable as the latter in cases where much protein is required in the food, as in case of heavily-worked animals, and must be supplemented by more highly nitrogenous materials. In fattening, on the other hand, and particularly in the fattening of swine, where a rather wide nutritive ratio is required, it produces excellent results. It is very probable that the comparatively large proportion of fat which it contains is one cause of its well-known fattening properties, though the effect of this is most likely not as great as is sometimes thought.

Numerous digestion experiments on hogs, sheep, and the horse, have shown that maize is very completely digested by all these animals. The results obtained on sheep and on the horse were substantially accordant; those on hogs, three in number, show a somewhat greater digestibility of the crude protein, but it is questionable whether this will be found to be generally the case.

§ 2. BYE-PRODUCTS OF THE GRAINS.

Since it is generally more profitable to the farmer to sell the comparatively high-priced grains than to use them for fodder, it comes about that their bye-products find an extensive application as fodder in place of the grains themselves, *e. g.*, the bran of wheat and rye, brewers' grains and malt sprouts from barley, etc.

Bran.—Bran has a high value for fodder, as is shown both by chemical analysis and microscopical examination; the latter, indeed, shows most strikingly how uneconomical is usually an extended use of grain for the food of those animals which do not, like the horse, demand a concentrated fodder. With cattle, particularly, it is more advantageous, as a rule, to feed the bran than the grain or meal; the raising of calves and the last stages of fattening form a partial exception to this rule.

If we investigate microscopically the way in which the several nutrients are distributed in the seeds of the cereals, we find that by far the larger part of the nitrogenous compounds is deposited in one or more definite layers of cells lying directly under the seed-vessel * and filled with fine grains of gluten. Wheat, rye, oats, and maize, have only one layer of protein-bearing cells, except in the neighborhood of the germ, while barley has three such layers under the seed-vessel.

In the manufacture of flour, the inner and starchy part of the grain is more easily pulverized during the process of grinding than the tough integuments. The latter are torn off, carrying with them portions of the layer of protein-bearing cells lying next to them, and are removed by bolting, constituting bran or middlings. As a consequence, the bran is richer in protein and the flour poorer, than the whole grain. Thus, the average composition of American wheat, wheat flour, and bran, in the water-free state, is as follows:

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* "The grains are properly fruits. Wheat and maize consist of the seed and seed-vessel closely united. Barley-grain, in addition to the seed-vessel, has the petals of the flower or inner chaff, and oats have, besides these, the calyx or outer chaff adhering to the seed."—("How Crops Grow.")

	Whole wheat. Per cent.	Wheat flour. Per cent.	Wheat bran. Per cent.
Ash	1.90	0.67	4.31
Protein	13.24	12.22	14.28
Crude fibre	84.86	87.11	7.60
Nitrogen-free extract			69.90
Fat			3.91

These figures show most plainly how uneconomical it must be, under most circumstances, to use the costly grains as fodder. Except in cases where a very concentrated food is required, the chief value of the grains lies in the albuminoids which they contain, since the non-nitrogenous nutrients can be far more chiefly supplied in roots and coarse fodder. The albuminoids, however, are contained in the cheaper bran in considerably larger proportion, and in view of this fact, the value of the latter as fodder becomes obvious.

Digestibility.—The digestibility of bran has been the subject of but few experiments, but it seems in general to be fully equal to that of the grains. The digestibility of wheat bran has been determined with sheep and oxen; that of rye bran only with swine.

Brewers' Grains.—In the preparation of malt liquors from grain, the starch which the latter contains is converted into sugar by the action of a peculiar ferment called diastase, contained in the malt, and this sugar is then fermented, and yields alcohol.

In this process it is chiefly the starch and a small quantity of extractive and flavoring matters which is withdrawn from the grain, while nearly all the protein is left behind. As a consequence, the residue is relatively richer in nitrogen than the grain, as is shown both by analysis and by microscopical examination, the latter showing the gluten cells intact, while the starch is nearly all dissolved out of the tissue containing it.

Brewers' grains are much more watery than the original grain. They contain about 24 per cent. of dry matter, and, on account of their richness in digestible albuminoids, have a narrow nutritive ratio. They seem to be very agreeable to cattle, and are an excellent fodder for fattening or for milk, while they are not adapted for animals that have to perform severe work.

Distillers' Grains.—In the manfacture of distilled liquors, the first stages of the process are essentially the same as in the preparation of malt liquors, but, after the fermentation, the mash is subjected to distillation to separate the alcohol. The residue remaining in the still constitutes distillers' grains or "slump." This has much the same composition as brewers' grains, except that it is more watery, containing only about 8 or 9 per cent. of dry matter. Like brewers' grains it has lost chiefly non-nitrogenous matters. It consequently has a narrow nutritive ratio, and is a valuable addition to fodder poor in protein. Moreover, it contains a considerable proportion of mineral matters, which may be of advantage under some circumstances.

Use.—Distillers' grains are best adapted for cattle, and yield excellent results in fattening or feeding for milk, when rightly used. For sheep, hogs, and horses they are not well suited.

In using this feeding-stuff, its watery nature should not be forgotten. Its relatively large proportion of protein renders it a suitable addition to a fodder deficient in this nutrient; while, on the other hand, the health of the animals requires the addition to the "slump" of some dry coarse fodder, like hay or straw. A poor quality of coarse fodder may be rendered more palatable to cattle by saturating it with distillers' grains, and thus the wateriness of the one fodder and the poverty of the other as regards protein can be simultaneously corrected.

Used in this way, distillers' grains constitute a perfectly healthful fodder. Much of the common prejudice against the use of "distillery slops" appears to be occasioned by their irrational application, and frequently by the filthy surroundings of the animals, rather than by anything injurious in the feeding-stuff itself.

Malt Sprouts.—Another bye-product of the breweries is malt sprouts. In the preparation of malt, barley is sprouted, and allowed to grow till the radicle attains a length equal to about two-thirds that of the grain; then the process is stopped by drying the malt, and the radicles either fall off of themselves or are removed by winnowing. These constitute malt sprouts; they are essentially very young barley plants. Now we have seen that, as a general rule, the younger a plant is the larger is the proportion of protein which it contains, and malt sprouts are no exception to the rule. As will be seen from the table in the Appendix, they contain about 24 per cent. of crude protein, and have a nutritive ratio of 1:2.5.

On the other hand, recent investigations have shown that they contain a large proportion of amides, as was indeed to be expected from what we already know of the functions of amides in germination. Five samples examined by Kellner* gave, by Sachsse's method, the following results on the water-free substance:

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* Biedermann's Central-Blatt, Jahrg. 8, p. 417.

Number.	Total nitrogen. Per cent.	Albuminoid nitrogen. Per cent.	Amide nitrogen. Per cent.	Amide nitrogen in per cent. of total nitrogen.
1	3.556	2.734	0.822	23.1
2	4.213	3.190	1.023	24.3
3	4.479	2.873	1.606	35.9
4	5.080	3.616	1.414	28.1
5	5.520	4.102	1.418	25.7

Malt sprouts serve excellently for bringing up the albuminoids of a ration composed of poorer materials to the desired standard, and are a favorite fodder for young animals and for milk and fattening. They are most suitable for cattle and swine. On account of their dry, brittle character, they are not well adapted for feeding directly, and need to be softened, either by mixture with watery fodder or by soaking in water.

§ 3. The Legumes.

Composition.—The seeds of the *leguminosæ* (beans, peas, vetches, etc.) are especially distinguished by their richness in protein, in which respect they exceed all other seeds. Their protein consists chiefly of the legumin described on p. 28.

The percentage of protein is not so variable in the legumes as in the cereals. The amount of this substance varies from about 22 per cent. to 30 per cent. of the dry substance, beans, and especially vetches, being generally somewhat richer than peas. The composition of each kind is given in detail in the table in the Appendix.

An exception to the range of variation given above is found in the lupine, especially in the seeds of the yellow lupine, in whose dry matter 32–48 per cent. of albuminoids has been found, while the seeds of the blue lupine are not so rich.

The very large amount of protein (the most costly nutrient) contained in the lupine, together with the fact, already referred to, that it can be cultivated on light soils, would render it a highly-prized feeding-stuff, were it not for its peculiar, bitter, disagreeable taste, and the injurious effects of the alkaloids which it contains.

Naturally, many attempts have been made to utilize this valuable and comparatively cheap material by removing the alkaloids, and thus rendering it palatable to other animals than sheep, which are the only animals that eat the raw grains readily. Various methods have been proposed, *e. g.*, roasting, or treatment with water to dissolve out the bitter matter. More effective than the latter is treatment with water to which a small quantity of muriatic acid has been added. In this case, however, the grain must be afterward boiled with pure water to which a little soda has been added to neutralize the excess of acid and prevent its purging the animals. The latter process is rather costly, and all these methods cause a not inconsiderable loss of nutritive matter, amounting, in one experiment, to 7.3 per cent. of protein and 6.3 per cent. of extract.

Digestibility.—The digestibility of beans has been made the subject of numerous experiments on ruminants, most of which have yielded fairly accordant results. The Weende experiments on oxen gave the coefficient 84 for the average digestibility of the protein, the most important ingredient. Later and rather more exact experiments have given somewhat higher numbers. Wolff's experiments on the horse, already several times alluded to, show that this animal digests beans as completely as sheep do.

The digestibility of peas has only been determined in experiments on swine. The results agree pretty closely with those obtained with beans in experiments on ruminants.

In some experiments by Hellriegel & Lucanus on the digestibility of lupines by sheep, the coefficients 97 and 81 for protein and nitrogen-free extract were obtained. In later experiments, by Stohmann, fully 90 per cent. of the protein of lupines was digested by goats; and it was at the same time observed that this bye-fodder aided the resorption of the non-nitrogenous constituents of meadow hay.

All the observations hitherto made show that the digestibility of the legumes is comparatively great, and that, on the average, at least for peas and beans, a coefficient of nearly 90 may be assumed for protein, and of 95 for the nitrogen-free extract.

Uses.—Unlike the grains, the legumes are disproportionately rich in protein, and may therefore be appropriately used to supplement fodder deficient in this substance and to bring the amount of albuminoids in a ration up to the desired standard. They form a very concentrated fodder, and, on account of their richness in protein, are well adapted for working animals and for fattening; but they should, if possible, form only a part of the grain ration. For milking and suckling animals they are less liked.

Lupines, when not submitted to some treatment to remove their bitter principle, are eaten most readily and with least danger of ill-effects by sheep and goats, while horses become accustomed to them less readily, and cattle hardly at all.

§ 4. OIL SEEDS AND OIL CAKE.

OIL SEEDS.—The seeds of certain plants, of which the most common are flax, rape (or colza), and cotton, contain large quantities of oil—flax containing 30–40 per cent., rape 35–45 per cent., and cotton about 30 per cent.—and are commercial sources of oil. These seeds are also rich in albuminoids, but they are not often used as fodder on account of their high price. Flax, however, is sometimes gathered when still unripe, in order to obtain a better quality of fibre, and in that case the seeds are comparatively poor in oil, and their price is so much lower that it would doubtless often be advantageous to use them for feeding. A fodder for young animals, for milk, or for fattening, if deficient in fat, can be essentially improved by such an addition, provided that the quantity of fat is not made too great. Generally, when it is desired to add fat to a ration, it can be effected to better advantage in this way than by the addition of pure oil. It must, however, be borne in mind that these seeds contain also large quantities of protein.

Digestibility.—No direct experiments have yet been made on the digestibility of oil seeds. It may, however, be assumed, until we have better data, to be the same as that of the corresponding kinds of oil cake.

OIL CAKE.—The high price of oil seeds prevents their general use as a fodder. They are chiefly applied to the production of oil, and only the residue from this manufacture is used for feeding purposes.

The oil is generally obtained by subjecting the seeds to hydraulic pressure, by which a large part of the oil is forced out, while most of the albuminoids remain behind.

The change effected in the composition of the material is analogous to that which takes place in brewers' grains, viz., a removal of the non-nitrogenous nutrients, here fat, while the greater part of the albuminoids remains.

It will be seen at once that the resulting oil cake must have a high nutritive value, since it contains all the protein of the original seed and that portion of the oil which cannot be removed by pressure. Its nutritive ratio is narrower than before, and it is better adapted for adding protein to a ration, since larger quantities of it can be used without danger of giving too much oil. At the same time, it is a highly concentrated fodder, and, like all such materials, must be used with caution, and only as a bye-fodder to supply the deficiencies of poorer materials.

Composition.—The composition of oil cake will, of course, vary according to the completeness with which the oil is extracted. The greater the pressure to which it is subjected, the less oil and the more, relatively, of albuminoids will it contain. A method of extracting the oil which has lately come into use to some extent consists in treating the ground seeds with benzol or bisulphide of carbon, which dissolve the oil. The residue from this process is poorer in oil and correspondingly richer in protein than that from the ordinary process of pressing, and it seems probable that it would have advantages as fodder over the latter. It is seldom that fat is deficient in the food of our domestic animals; but it is often desirable to increase its protein, and by means of the extracted oil cake we could accomplish this without unduly increasing the amount of oil.

The average of all analyses of American oil cake yet made are as follows, calculated on the water-free substance:

	Linseed cake. Per cent.	Cotton-seed cake. Per cent.		Linseed cake. Per cent.	Cotton-seed cake. Per cent.
Ash	7.13	7.33	N. fr. extract	37.66	19.98
Protein	32.48	46.17	Fat	13.03	18.54
Crude fibre	9.70	7.98			

But one sample (of linseed cake) contained less than 10 per cent. of fat; but in that one the amount was only 3.15 per cent., while that of the protein was 39.92 per cent., showing that the sample had been extracted in some manner. Cotton-seed cake, it will be seen, is considerably richer in protein and fat and poorer in nitrogen-free extract than linseed cake, and must have a correspondingly higher feeding value.

Palm-nut cake contains less albuminoids and more nitrogen-free extract than linseed or cotton-seed cake, while the percentage of fat is about the same. It forms an excellent fodder, being very palatable and producing excellent results.

Digestibility.—The numbers given in the Appendix for the digestibility of linseed cake are the average results of numerous experiments on sheep, goats, and oxen, made in Hohenheim, Halle, and Möckern, respectively, and agreeing well with each other.

The digestibility of cotton-seed cake has been tested in experiments on sheep in Hohenheim. The material used came from Egypt, and was of poor quality compared with that sold in our markets. It contained numerous fragments of leathery pods, which brought the amount of crude fibre up to 27.61 per cent., while it contained only 26.24 per cent. of protein. It seems somewhat doubtful whether results obtained on such material would be fully applicable to our cotton-seed meal; but these are the only experiments yet made, and we must accept their results till better are available.

The digestibility of palm-nut meal has been tested in Möckern, in experiments on cows, and in Hohenheim, on sheep. The results showed that the digestibility of this feeding-stuff is great, ranging above 90 for all the ingredients. It is also distinguished for its palatability and its favorable action on milk-production and fattening.

Uses.—Unlike most of the feeding-stuffs hitherto considered, the various kinds of oil cake are excessively rich in protein and deficient in non-nitrogenous nutrients. This is especially the case with those which have been prepared by some process of extraction, the nutritive ratio being sometimes as narrow as 1 : 1. The more common kinds of oil cake, while containing considerable fat, and hence having a wider nutritive ratio, are still characterized by a large excess of protein.

Obviously, then, oil cake is particularly valuable as a source of protein and as a means of increasing the amount of this substance in a ration. Many of the cheaper forms of coarse fodder, while furnishing large quantities of non-nitrogenous nutrients, are deficient in protein. This deficiency may be readily supplied by the addition to them of a comparatively small amount of oil cake, and thus the deficiencies and redundancies of the two fodders be made to supplement each other. For example, it would not be difficult to compound from straw and oil cake a mixture which should contain the same proportions of digestible matters as the best hay, and in most cases at a cost considerably less than that of the latter. Moreover, the addition of such a nitrogenous bye-fodder to the straw would probably secure a more perfect digestion of the straw itself.

The value of oil cake for feeding, when properly used, particularly in feeding for milk and in fattening, is not easily overestimated. Cotton-seed cake or meal, especially, deserves the attention of our farmers. It is the richest of the common kinds of oil cake, is readily obtainable, and, after passing through the body of the animal, still retains nearly all its value as a fertilizer, in which respect it is nearly equal to average fish scrap.

As already stated, palm-nut cake is less rich in protein than the other varieties of oil cake, but it nevertheless contains a considerable proportion of that substance. It appears to be specially adapted for milk cows, and does not impart any undesirable properties to milk or butter.

Oil cake in general is chiefly used for milk animals and for fattening, experience having shown that for working animals it cannot take the place of grain. It is hence particularly valuable for cattle, sheep, and hogs, while for horses it is little used.

§ 5. ANIMAL PRODUCTS.

Flesh Meal.—A feeding-stuff which has lately found extensive use in Europe, and which, both in virtue of its richness in protein and its easy digestibility, ranks as the most concentrated of fodders, is the so-called American flesh meal.

It consists of the dried and ground residue from the manufacture of Liebig's Extract of Meat, in South America: it contains, in the air-dry state, ten to thirteen per cent. of water, and in the dry substance eighty-two to eighty-three per cent. of protein, along with thirteen to fourteen per cent. of fat. It has thus far been used chiefly for swine, though to some extent for other animals.

In experiments on the former, by Wolff (see page 276), in which the flesh meal was fed in quantities of one-half to one pound per day, along with potatoes, the average digestibility of the flesh meal was found to be:

Protein	97 per cent.
Fat	86 "
Total organic matter	92 "

Flesh meal being so digestible, it is easy to see that it must exert an excellent effect, especially when used in small quantities, perhaps half a pound per day and head, as an addition to a fodder otherwise poor in protein; that is, when used to bring up the quantity of protein in the total fodder to the desired standard.

Flesh meal is the more valuable, practically, for swine, because by means of it the animals can be induced to eat large quantities of other fodder, in particular potatoes. Moreover, the addition of a nitrogenous bye-fodder to a feeding-stuff containing much starch, like potatoes, contributes essentially to ensure the complete digestion of the latter. (Compare page 282.)

The use of flesh meal is not confined to swine, however; it has also been used with good results for milk cows and for fattening cattle. The animals at first generally refuse to eat the flesh meal, but when it is fed in small amounts, and gradually increased to 2 to 3 lbs. per day, they soon become accustomed to it and come to eat it even greedily. Sheep have in most cases obstinately refused it, but occasionally they have been accustomed to it, and it has produced good results. The digestibility in these cases has been found to be fully as great in Wolff's experiments on swine.

Some interesting experiments have recently been made by Wolff,* to determine the nutritive value of the protein of flesh meal as compared with vegetable protein. The experiments were made on swine. The vegetable protein was furnished in the form of peas, to which a small amount of oil was added; to the flesh meal enough pure starch was added to give the mixture nearly the composition of the peas. In each case four kilogrammes of potatoes per day and head were fed. The experiments continued 182 days; their results, while not entirely decisive, showed that practically the same gain of live-weight was produced by the one ration as by the other under like conditions, and thus indicated that animal and vegetable protein have an equal nutritive value.

All these trials are very interesting as showing that the animal organism is indifferent to the source of the protein which it receives, and that the difference between the herbivora and carnivora is not that the one can eat only vegetable and the other only animal food, but that the digestive apparatus of the former is adapted to large masses of fodder, while the comparatively short alimentary canal of the latter requires a very concentrated food. The herbivora are capable of digesting and utilizing animal protein, if it is mixed with a suitable amount of coarse fodder, and, on the other hand, it is a well known fact that the dog and cat, both carnivorus animals, can subsist on the more concentrated forms of vegetable food.

Fish Guano or Fish Scrap.—The residue from the preparation of oil from various kinds of fish, which is extensively used as a fertilizer under the name of fish guano or fish scrap, has also been tested as a feeding-stuff, with favorable results. The German experiments have been made on the so-called Norwegian fish guano, which is stated to contain about 2 per cent. of fat and 12 to 15 per cent. of phosphoric acid, and must therefore be a different preparation from that sold in our markets, which generally contains from 7 to 15 per cent. of fat and 6 to 8 per cent. of phosphoric acid.

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* Landw. Jahrbücher, VIII., I. Supplement, 223.

The first experiments were made on sheep by Weiske,* and it was found that the fish guano constituted a very good bye-fodder which had the advantage over flesh meal that it was eaten more readily by the animals. Fully a third of the nitrogenous matter of the fish guano consisted of gelatigenous substances, which are not fully equal to the albuminoids as food (see p. 162); but the experiments showed that, on account of its easy and great digestibility, the fish gave an even better nutritive effect than a ration of hay and oats containing the same amount of crude protein. The digestibility of the fish guano was not accurately determined in this investigation, but it was estimated that from 77 to 83 per cent. of its nitrogenous matter was digested.

Later experiments by Kellner,† also on sheep, gave a digestion coefficient of 90 for the total nitrogenous substance, and showed that at least 75 per cent. of the gelatigenous matter of the fish was digested. It was also found that the phosphoric acid which is present in large quantities in fish, although not digested to any great extent, was made more soluble by passing through the digestive apparatus and thus acquired an increased manurial value. When we add to this the fact that the nitrogen, after having fulfilled its functions in the body, is nearly all excreted in the urine in a form quite as available for vegetation as before, the gain attainable by using the fish as fodder becomes plain.

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* Jour. f. Landw., XXIV., 265.

† Landw. Versuchs-Stationen, XX., 423.

Little experience has yet been had concerning the effect of fish on the quality of animal products. It is perhaps to be anticipated that it would injuriously affect the flavor of milk, but it seems probable that it would form an excellent fodder for fattening. It does not appear to have been used as fodder to any extent in this country. In the "Report of the Secretary of the Maine Board of Agriculture" for 1864, some account is given of its use as fodder for sheep, hogs, and fowls, and in subsequent reports of the same board its use is again mentioned, but the writer is not aware that it has elsewhere become a recognized article of cattle food. In Norway, fish is said to be used to a considerable extent as food for cattle, and in a book on Iceland, published over one hundred years ago,* the use of fish for feeding cows is mentioned.

It would be of interest to test the value of this feeding-stuff further, and also to experiment on the use of fish guano from which the oil is more completely extracted than from the common article, *e. g.*, that produced by Adamson's or Goodale's process.

Dried Blood and Meat.—A few experiments on this material as a feeding-stuff have been made by Wildt.† The material contained 91.87 per cent. of protein, and the digestion coefficient for this substance was found to be for swine 72 and for sheep 62, the rest of the fodder being in one case potatoes and in the other barley straw.

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* "Natural History of Iceland," by N. Horrebow, London, 1752.

† Landw. Jahrbücher, VI., 177, and Landw. Versuchs-Stationen, XX., 21.

The dried blood was very hard and solid, and it is probable that by finer grinding and suitable preparation, such as soaking in water or cooking, a greater digestibility could be reached. The portion actually digested by the swine seemed to exert the same nutritive effect as an equal amount of vegetable protein in the form of peas.

In this country, dried blood and meat scrap have been used in feeding trials by Mr. J. W. Sanborn,* with favorable results.

The chief value of all these materials lies in their high percentage of protein, and the proper use of such feeding-stuffs is as an addition to fodder poor in protein, as was explained in the section on oil cake. The choice between the various kinds of nitrogenous bye-fodders will be determined by various circumstances, such as their palatability, dietetic effect, influence on the quality of the products, cost, etc., and must vary in different cases, but the principle underlying their use is always the same.

Bye-products from Milk.—The chief of these is the whey, from the manufacture of cheese, which is chiefly used for hogs.

The manufacture of cheese consists essentially in coagulating the casein of the milk by means of rennet. The curd thus formed encloses in itself much of the fat of the milk, and the resulting whey contains about 1 per cent. of protein, 4 to 6 per cent. of milk sugar, and 0.3 to 0.6 per cent. of fat. The nutritive ratio is, therefore, not very wide, though it is variable, according to the completeness with which the albuminoids are separated in the curd. Water, of course, is the chief ingredient, amounting to about 90 per cent., or over.

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* Farm experiments at the New Hampshire College of Agriculture.

For hogs, whey is a very palatable and excellent fodder, especially if its very watery consistence be reduced somewhat by the addition of grain. Indeed, many feeding-stuffs, like bran or oats, which of themselves are less adapted to these animals, seem to be better utilized when thus fed with whey than when used alone.

Far more nutritious than whey are skimmed milk and sour milk, the first having lost chiefly fat and the second nothing. They have a narrow nutritive ratio, and with their help large quantities of potatoes and other feeding-stuffs poor in protein can be very completely digested and utilized.

All the constituents of milk may be regarded as wholly and easily digestible, except, perhaps, when it forms the exclusive food, when small quantities may escape digestion or resorption.

§ 6. Tubers and Roots.

General Properties.—The feeding-stuffs which we have hitherto considered in this chapter either have a medium nutritive ratio, or contain an excess of protein. Tubers and roots, on the other hand, contain an excess of the non-nitrogenous nutrients, starch predominating in the former, and sugar and pectin in the latter. As we regarded other feeding-stuffs as concentrated because they contained in a small bulk large quantities of digestible protein, so we may call these also concentrated, because they contain, in a small bulk, large quantities of digestible carbhydrates.

Of the tubers, the one of greatest importance is the potato. It is a thickened underground stem, in which large quantities of starch have been laid up to serve as food for the new branches, leaves, and fruit which are to develop from it. In like manner, the roots (turnips, beets, carrots, etc.) are reservoirs of food for the young plants, but are, however, really roots and not stems.

Besides their large content of non-nitrogenous nutrients, these feeding-stuffs contain a large amount of water, viz., on the average:

Potatoes	75.0	per cent.
Sugar beets	81.5	"
Carrots	85.9	"
Rutabagas	87.0	"
Mangolds	88.0	"
Parsnips	88.3	"
Turnips	91.5	"

Potatoes are decidedly less watery than roots, while, of the latter, turnips contain the most water and the others about the same quantity, the slight differences shown by the above averages of all trustworthy analyses being of no significance.

These considerations indicate clearly the proper method and limits of the use of root crops as fodder. Just as the feeding-stuffs previously considered are adapted to furnish albuminoids, and so to narrow the nutritive ratio of a ration, so these are admirably adapted to furnish carbhydrates in an easily digestible form, and to widen the nutritive ratio.

Neither kind of fodder can be used alone. Each can supply the wants of the organism in one particular direction, and one only. In order to obtain good results from roots, they must be fed along with other and more nitrogenous fodder. For this there are two reasons—first, roots are unable of themselves to supply enough protein for the needs of the animal, containing as they do but a trifling quantity; and second, without the addition of more protein to the ration much of the non-nitrogenous nutrients of the roots is liable to escape digestion. Still further, roots are a very watery fodder, and do not possess the necessary volume to fit them to serve as the exclusive food of ruminating animals. Hence, they must have added to them a certain amount of hay, straw, or other dry fodder, as well as some nitrogenous bye-fodder. A ration might be compounded, for instance, from mangolds and oil cake, which should contain protein, fat, and carbhydrates, in sufficient quantity and in the right proportions to supply the demands of a milk cow; but it would scarcely be regarded as suitable for such an animal.

With hogs the case is different. Potatoes, especially, seem to agree excellently with these animals, and when enough of some substance rich in protein, such as flesh meal, is added, to establish a suitable nutritive ratio and ensure the digestion of the starch, they produce excellent results.

Proportion of Non-protein.—Comparatively recent investigations have shown that a large part of the nitrogenous matter of tubers and roots consists of various forms of "non-protein," among which nitrates and amides are particularly abundant.

Various experimenters have noticed the occurrence of amides or related bodies, as well as of nitrates and ammonia salts, in beets, but the first thorough investigations of the nitrogenous constituents of fodder beets were those of Schulze & Urich. In their first investigation [*] they confirmed the fact already known, that beets contain a relatively large but variable quantity of nitrates, corresponding, in their experiments, to from 10 per cent. to 47 per cent. of the total nitrogen, and also found a very considerable quantity of amides, while only 21.6 to 38.9 per cent. of the total nitrogen belonged to albuminoids.

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[*] Landw. Versuchs-Stationen, XVIII., 296.

The following statement of their results on one sample will serve to give an idea of all:

	Per cent. of fresh substance.	Per cent. of total nitrogen.
Total nitrogen.............	0 2390	100.00
Nitrogen in soluble albuminoids..	0.0358	14.98
" insoluble "	0.0158	6.61
" amides............	0.0857	35.86
" nitrates...........	0.1053	44.06
" ammonia salts.......	0.0050	2.09
	0.2476	103.60
Error.....................	0.0086	3.60

In their second paper,* the same authors showed that among the amide-like bodies contained in beets was glutamin, and a trifling amount of asparagin. They also investigated the functions of the amides, with the results already stated on page 37.

A considerable amount of non-albuminoid nitrogen has also been found in the potato by Schulze & Märcker† and by Kreusler,‡ and more recently Schulze & Barbieri§ have published more extended investigations of five sorts of potatoes, which showed that the nitrogen of the fresh substance was distributed as follows:

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* Landw. Versuchs-Stationen, XX., 193.

† Jour. of Landw., 1872, p. 66.

‡ See the paper by Schulze & Barbieri.

§ Landw. Versuchs-Stationen, XXI., 63.

	Nitrogen of insoluble albuminoids. Per cent.	Nitrogen of soluble albuminoids. Per cent.	Nitrogen of amides. Per cent.	Nitrogen of unknown compounds. Per cent.
I.	0.069	0.143	0.125	0.012
II.	0.046	0.157	0.118	0.019
III.	0.058	0.080	0.143	0.010
IV.	0.047	0.115	0.150	0.024
V.	0.087	0.147	0.100	0.026

The distribution of the nitrogen between protein and non-protein was, therefore:

	Protein. Per cent.	Non-protein. Per cent.		Protein. Per cent.	Non-protein. Per cent.
I.	60.7	39.3	IV.	48.2	51.8
II.	59.7	40.3	V.	65.2	34.8
III.	47.4	52.6			

Beets and potatoes appear to be the only root-crops whose nitrogenous constituents have been investigated, but it is highly probable that other roots and tubers also contain considerable amounts of amides. Naturally, the bye-products, such as "potato slump," beet-root molasses, etc., are also liable to contain the same or derived bodies.

TUBERS.—**Potatoes.**—The composition of potatoes is largely determined by the variety and by various external circumstances, such as soil, weather, and manuring. They may contain from 18 to 30 per cent. of dry matter, from 1.3 to 4.5 per cent. of protein, and from 12 to 27 per cent. of starch.

The richer a potato is in starch the poorer it generally is in protein; the more watery it is the less is its percentage of starch, and the greater, as a rule, is the amount of protein, and usually also of ash.

When normally developed, the potato contains at least 25 per cent. of dry matter, and the nutritive ratio is 1 : 10 –12. Grown in a very rich soil or in a wet clay, the same variety of potatoes contains far less starch, but is richer in protein than when grown in a sandy soil or a sandy loam. A soil rich in humus sometimes produces much larger potatoes than a sandy soil, but their content of starch is generally less than that of medium-sized tubers grown in the same soil.

This variation in the percentage of starch according to the size of the tubers, vanishes, the more closely the soil approaches the sandy or loamy character, so that in potatoes grown in such soils the content of starch often increases with the size, especially if the smaller ones are not fully ripe.

It is also well known that the manuring exercises an important influence on the quality and chemical composition of the potato. According to one observation, *e. g.*, the same variety of potatoes contained 2.27 per cent. of protein when manured with potash and lime, and 4.44 per cent. when heavily manured with carbonate of ammonia.

The same thing, however, is true of the potato as of other crops, viz., that the influence of the manuring on the quality of the crop varies according to the other influences which act with it, such as soil, weather, and method of culture. According to whether these aid or hinder the action of a manure or chemical fertilizer on the composition of the tubers, the effect produced will be more or less striking.

It may be added that the ash of the potato is rich in potash and contains also considerable phosphoric acid, but only a little lime and soda; this must be borne in mind when they are used for feeding milk cows or young and growing animals.

Artichokes.—These may be mentioned as being the only other tubers which are of practical importance as fodder, and even they are seldom raised on the large scale.

The tubers of this plant are more watery than the potato, but somewhat richer in protein, so that the nutritive ratio is on the average about 1 : 8. The stalks may also be used as fodder for sheep, the animals being allowed to select for themselves the leaves and tender plants.

ROOTS.—**Composition.**—Potatoes and artichokes are tubers, though often included under the term roots or root crops.

The feeding-stuffs which we are about to consider, however, are true roots, and the difference shows itself even in their chemical composition, while among themselves they are so similar that a separate consideration of each kind is hardly necessary.

They contain much more water than the tubers, and are characterized by the fact that while in the former the nitrogen-free extract consists almost wholly of starch, in the roots it consists of sugar and bodies of the pectin group, with no starch except in a few cases, *e. g.*, in the carrot.

That pectin is easily digestible, at least by ruminants, was found in experiments made long ago, by Grouven, at Salzmünde, on oxen, and this result has been confirmed by the fact that in numerous experiments since made on sheep, in Hohenheim, the nitrogen-free extract of roots was very completely digested, often up to 98 per cent., even when large quantities of roots were fed. The nutritive effect, therefore, of the nitrogen-free extract of roots may be assumed to be similar to that of starch.

Variations in Composition.—It is observed in all roots that, other things being equal, the water content increases with the size of the root, and consequently the quantity of dry matter decreases.

The richer the soil and the more heavily it has been manured, especially with yard manure, the greater is usually the percentage of protein in the dry matter of the roots. The different kinds of roots, however, show differences in this respect. Sugar beets are the poorest in protein and contain the most dry matter, at least when they develop according to the wish of the sugar manufacturer. Large sugar beets, weighing two pounds and over, such as are produced by heavy green manuring and too wide setting, have a composition more resembling that of ordinary mangolds.

Feeding Value.—The foregoing consideration of the chemical composition of tubers and roots points out unmistakably their true value as fodder. Aside from their succulence and palatability, and any specific dietetic action which they may exert, their value lies in their non-nitrogenous ingredients. They contain but little nitrogenous matter and only a portion of this is true protein, so that unless very large amounts of them are fed these constituents are of little account. The carbhydrates and pectin substances which they contain, on the other hand, are present in large quantities, are easily digestible, and furnish a ready source of non-nitrogenous nutrients.

These feeding-stuffs are generally assumed to be wholly digestible. It is not likely that this is strictly true, but their digestibility is so great that no serious practical error is involved in the assumption of complete digestibility.

Sugar Beet Pulp.—Where the manufacture of beet sugar is carried on, the residue from the extraction of the juice is largely used as fodder.

The change of composition which takes place in the material consists largely in a removal of non-nitrogenous constituents; but the extent of the alteration, as well as the composition and properties of the residue, vary considerably according to the method of manufacture.

In the older methods, still quite commonly used, the juice is obtained either by pressing the roots or by means of a centrifugal machine. In both cases more or less of the nitrogenous matter of the beets passes into the juice. Sugar beets have, on the average, a nutritive ratio of 1 : 17; in the residues thus obtained it is reduced to 1 : 10–12, while the pressed residue has about 30 per cent., and that from the centrifugal machines about 18 per cent. of dry matter.

The newer method consists in treating the thinly sliced roots with warm water and allowing the sugar to diffuse out. In this method but little protein passes into the juice, and the residue has a much narrower nutritive ratio than that from either of the former methods, viz., 1 : 5.5–7, rendering it, of course, all the more valuable for feeding. It has, however, the disadvantage of being very watery, containing only about 5.5 per cent of dry matter; by moderate pressure the amount may be increased to about 7 per cent., and by heavier but more costly pressure to 9.5 to 14.5 per cent.

A process strongly recommended for utilizing these residues is to remove as much of their water by pressing as practicable and then to treat them by ensilage.

In the fermentation still more water is removed, but, according to experiments in Weende, only a slight loss of valuable nutrients takes place, and this is less when the residue is previously pressed than when it is submitted to fermentation in its fresh state. In these experiments the percentage of dry matter increased, in the unpressed residue, from 5.4 to 8 per cent., and in the moderately pressed residue from 6.8 to 13.7 per cent. A further advantage in pressing previous to fermenting is that it seems to make the fodder keep better and to protect it from decay.

The residue of the diffusion process, when fermented, is an excellent and palatable fodder for all farm animals, when it is fed as part of a properly compounded ration, while it does not seem to be so satisfactory when fed fresh.

PART III.

THE FEEDING OF FARM ANIMALS.

CHAPTER I.

FEEDING STANDARDS.

Components of Body.—In the first chapter of Part I. we learned that the animal body, in spite of the great number of different substances which are found in it, may be regarded, for purposes of feeding, as composed of four substances, viz., water, protein, fat, and ash. All the other compounds which it contains are found in such small quantities as to be of no significance when the general make-up of the body is under consideration.

In life the body suffers a continual loss of these substances, and must receive a constant supply of materials from without to replace them. The loss of water is readily supplied, and any fodder which is adequate in other respects will in most cases contain a sufficient amount of the ash ingredients; so that in feeding, our attention is chiefly devoted to supplying materials for replacing the losses of protein and fat to which the body is subject.

The Nutrients.—The replacement of these continual losses from the body, as well as the supply of material for new growth, is accomplished by means of the food.

Plainly, however, it is not the food as a whole, but those ingredients of it which are *digested* which can serve this purpose. Neglecting, as before, water and ash, the substances digested and resorbed from the food are essentially three in number, viz., protein, fat, and carbhydrates; and it is with these three kinds of matter that the amount of protein and fat in the body is maintained or increased. The digested protein of the food is the sole source of the protein of the body, while, as we have seen, the investigations thus far made lead us to the conclusion that all three groups of nutrients probably contribute to the formation of fat.

Feeding Standards.—In the last three chapters of Part I. we took up the general laws regulating the production of flesh, fat, and work in the body. It became evident from the considerations there presented (compare page 196) that an essentially different proportion of nitrogenous and non-nitrogenous nutrients is required in the fodder according to the object of the feeding, a conclusion which is plainly in harmony with practical experience.

The chief object of investigation in the field of cattle-feeding was there stated to be the determination of the quantity and proportions of the several nutrients required in the fodder of animals kept for various purposes. The results of such investigation are concisely expressed in what are called "Feeding Standards," which are simply statements of the amounts of digestible protein, carbhydrates, and fat, which experience has shown to be in general best adapted to the purpose in view. For example, the feeding standard for milk cows given by Wolff is as follows:

FEEDING STANDARD FOR MILK COWS, PER DAY AND 1,000 POUNDS LIVE WEIGHT.

Digestible protein	2.5 pounds.
" fat	0.4 "
" carbhydrates	12.5 "
Nutritive ratio	1 : 5.4
Total dry matter	24 pounds.

This means that any mixture of suitable feeding-stuffs from which a cow can digest 2.5 pounds of protein and 13 pounds of non-nitrogenous nutrients per day will form a proper ration and yield a good flow of milk.

Advantage of Feeding Standards.—The advantage of a feeding standard lies in the fact that it presents the results obtained by careful experiment and observation in a concise form, and one admitting of practical application.

Thus the feeding standard for milk cows given above is deduced by Wolff from the results of a large number of experiments made at different times and by different observers In these experiments various feeding-stuffs were used. Now it is plain that a simple statement of the kind and quantity of fodder used in one or all of these experiments would be of use to the feeder only if he had at his disposal the same kind and quality of fodder. If, on the other hand, he must use other feeding-stuffs, he can derive no benefit from these experiments unless he has some means of comparing the nutritive value of his feeding-stuffs with that of those there used.

This he can do by estimating the amounts of the several nutrients which his feeding-stuffs contain in a digestible form, since it is evident that their nutritive value lies simply in the amount of protein, fat, and carbhydrates which the cows can extract from them. Moreover, when he knows the quantity of digestible nutrients which his feeding-stuffs contain, a feeding standard like that already given will enable him to compound a ration, from the materials at his disposal, which shall supply his cows with the same amounts of digestible matters as were employed, on the average, in the experiments from which that standard was deduced. When his cows are thus fed, though they may not consume the same kind or weight of fodder as was used in the experiments which he has taken for a model, they will resorb into their systems the same amounts of protein, fat, and carbhydrates, and will therefore be equally well nourished.

The method of calculating rations in accordance with these principles will form the topic of a subsequent chapter; we are concerned here only with the nature and utility of feeding standards.

The convenience of these standards as a means of expressing the results of experience and as a guide in the compounding of rations is obvious. In the succeeding chapters we shall occupy ourselves with a consideration of the feeding standards for the various purposes for which stock is kept, endeavoring to indicate the degree of confidence which is to be placed in them and the principles in accordance with which they may be modified to suit individual circumstances.

In addition to the amount of digestible nutrients required, feeding standards usually prescribe approximately the amount of total dry matter in the ration. This, in connection with the amount of digestible matters, informs us in regard to the volume of the ration, and whether it contains larger or smaller quantities of coarse or of concentrated feeding-stuffs. If the amount of total dry matter is much in excess of the sum of the digestible matters, it is obvious that a considerable portion of the ration must be made up of bulky fodder, containing much indigestible matter and serving to make up the necessary volume, while if this excess is small, a larger portion of the ration must consist of easily digestible feeding-stuffs.

In the feeding standard given above as an illustration, a certain quantity of digestible fat is called for. It is at present impossible to state with any certainty the most suitable quantity of this substance, since so few experiments have been made on the subject, and even these are by no means accordant. We know that the fat of the food appears to be more easily stored up in the body than that coming from the splitting up of the albuminoids (page 191), and that fat is a more concentrated heat-producer than the carbhydrates, while, in its relations to the gain and consumption of flesh, it can be replaced by the latter. It may, therefore, be assumed that the fat of the fodder plays a direct and important part in the production of milk, in fattening, and in the feeding of working animals, especially horses, and that accordingly where a rapid production is desired, the amount of fat in the ration is of some moment. We shall, therefore, include the digestible fat as such in the feeding standards, but rather as an indication of its probable importance than as a statement of the quantity of it which must be contained in the ration.

Limitations of Feeding Standards.—Feeding standards being simply the concise expression of the results of experiment and observation, it is plain that their value must depend on the extent and accuracy of the observations on which they are based. Some of those to be considered in the following chapters are the results of many careful experiments, and are worthy of much confidence. Others, again, are based on but few observations, and are confessedly only tentative.

Furthermore, it is plain that a single feeding standard cannot possibly take account of all the varying conditions that arise in practice. For the maintenance of full-grown animals it is possible to give tolerably exact feeding standards, but for purposes of production it is obvious that an important factor in determining the character of the feeding is the amount of production which is desired, this again being determined by financial considerations. As a general rule, a rapid and abundant production is relatively more expensive than a smaller and slower one, and is profitable only when the price of the products is correspondingly high.

Moreover, different breeds, and even different animals of the same breed, show differences in their capacity for production and in the return which they yield for a given expenditure of fodder.

Under these circumstances the office of a feeding standard is to show what amount and quality of food is *in general* best adapted to the end in view, while the conditions of the individual case must determine how far and in what way it is to be modified. An *unintelligent* use of feeding standards is quite as likely to result in failure as in success; but when combined with practical judgment and observation, and knowledge of the laws of animal nutrition, they are capable of rendering important aid to the feeder.

In the following chapters we shall take up the chief objects of feeding and consider briefly the application to them of the general laws of animal nutrition which formed the subject-matter of Part I., indicating under each head the quantities of the several nutrients (*i. e.*, the feeding standard) which the experience thus far had shows to be, on the whole, adapted to produce the best results at the least expense of fodder.

Amides.—Attention has already been several times called to the fact of the existence of considerable amounts of amides in many fodders. Many of the experiments from which our feeding standards are derived have, doubtless, been made with such fodders, and it becomes of interest to inquire how their results are affected by this fact.

It is to be remembered that these feeding standards are not deduced from any theoretical considerations, but are simply the combined results of more or less numerous carefully conducted feeding-trials. In these trials, feeding-stuffs have been used which have subsequently been shown to contain amides, and their results, when allowance is made for this fact, might be expressed somewhat as follows:

So much digestible albuminoids *and amides*, along with such and such amounts of digestible carbhydrates and fat, proved a suitable ration for the purpose intended.

Now in compounding a ration in accordance with a feeding standard like the above, the farmer would naturally use, to a considerable extent, feeding-stuffs similar to those used in the original experiments, and in all probability the proportions of albuminoids and amides in the two rations would not vary very greatly.

Moreover, it would appear from our present knowledge that any difference which might exist would only affect the value of a ration as a fat producer, while the two rations would be on an equality as regards the formation of flesh.

If we add to this the fact that the feeding standards themselves are but approximations, and are not to be blindly followed, but intelligently modified to suit varying circumstances, we shall see that, in spite of some ambiguity, a feeding standard may yet be a valuable aid in apply-ing the experience gained by other experimenters to our own particular case.

Still further, if we know, as we easily may, the proportions of albuminoids and of amide-like bodies in the feeding-stuffs which we use, we have, even with our present limited knowledge of the subject, the basis for forming a tolerably intelligent judgment as to whether our ration is deficient in true albuminoids or not.

It is, of course, desirable that feeding standards should distinguish between albuminoids and amides, and doubtless this will be done to a large extent in future investigations. Meanwhile, the considerations here presented show that those standards which we possess at present are far from having lost their practical value when intelligently used.

Subjects not Considered.—Regarding, as we do, the determination of the proper feeding standards for the various purposes of feeding as the chief object of all work in this department of agricultural science, we must confine ourselves in this part of the present work chiefly to the consideration of these standards. It does not come within the scope of this work to consider such questions as the palatability of the various feeding-stuffs, the most suitable kinds of fodder for different animals, or any "specific" or dietetic action of particular fodders on the organism. These are, in part, purely practical questions, and in part questions to which science can as yet return no definite answer. Consequently, though they are often of great importance, they do not properly find a place in a work which treats of the application of science to feeding.

Furthermore, it is not our purpose to consider the necessary management and care of stock, the arrangement of stalls, stables, and yards, or the various methods of preparing the fodder. On the contrary, we assume that all that is necessary in these respects is carefully observed; only when this is the case can the best attainable utilization of the fodder used be expected. In this we include those methods of preparing the fodder which, while they do not increase its digestibility, render it more palatable, and incline the animals to eat more of it.

CHAPTER II.

FEEDING FOR MAINTENANCE.

§ 1. OXEN.

The Weende Experiments.—In order to obtain the necessary basis for a rational feeding of domestic animals, especially of the ruminants, it is important to determine the minimum amount of nutritive matters which is necessary for full-grown animals in complete rest, in order to just keep them in average condition. Oxen are especially adapted for such experiments, since in these animals the production of hair or other portions of the body, or of secretions like milk, does not demand any considerable quantity of nutrients, and therefore the demands of the vital processes on the latter can be determined with sufficient accuracy.

The earlier experiments of Henneberg & Stohmann,* at Weende, gave valuable results on this point. They were made on full-grown oxen; the digestibility of the fodder was ascertained directly, and the protein consumption and the gain or loss of flesh were also determined. In the absence of a respiration apparatus, the gain or loss of fat could only be estimated.

It was observed that the whole outward appearance of the animals remained unchanged for a considerable time, and that their weight suffered no essential increase or decrease, when they received, per 1,000 lbs. live weight, one of the following rations per day:

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* "Beiträge zur Begründung einer rationellen Fütterung der Wiederkäuer," Heft 1.

1. 19.5 lbs. clover hay.
2. 3.7 “ “ “ 13.0 lbs. oat straw, and 0.6 lb. rape cake.
3. 2.6 “ “ “ 14.2 “ “ “ 0.5 “ “
4. 3.8 “ “ “ 13.3 “ rye straw, and 0.6 “ “
5. 25.6 “ mangolds, 12.6 “ oat straw, and 1.0 “ “

These rations were found to have yielded the following quantities of digestible nutrients per day:

	Temperature of stall. Deg. Fahr.	Protein. Lbs.	Fat. Lbs.	Carbhydrates. Lbs.
1.............	50.7	0.84	0.04	7.61
2.............	61.7	0.56	0.04	7.12
3.......	68.7	0.41	0.25	7.52
4.............	68.7	0.49	0.46	7.03
5.............	61.7	0.56	0.60	6.44
Average....	62.3	0.57	0.28	7.14

It was furthermore observed that there was rather a slight gain than any loss of flesh, showing that the fodder was certainly sufficient to maintain the animals in their original condition. In only one of the experiments was a small loss of flesh observed, and this took place in Experiment 1, in which the greatest quantity of nutrients was digested. It is probable that this is to be explained by the lower temperature of the stall in this case, since a lower temperature causes an increased production of heat in the body at the expense of either the food materials or the body itself. It may be mentioned, also, that the above rations contained, on the average, about 0.05 lb. of phosphoric acid, 0.1 lb. of lime, and 0.2 lb. of alkalies, quantities which must be abundantly sufficient to supply the wants of full-grown oxen at rest. The daily amount of water was, per 1,000 lbs. live weight, 52 to 64 lbs., averaging 55 lbs.

No certain evidence could be obtained in the above experiments as to whether the fat of the body, like the flesh, remained unaltered in amount; this could only be assumed as probable from the general appearance of the animals.

The average nutritive ratio in these experiments was 1 : 13. Later experiments in Weende showed very decisively that a much narrow nutritive ratio is undesirable in the maintenance feeding of oxen. In the average of thirteen experiments the animals digested, per day and 1,000 lbs. live weight, 1.18 lbs. of protein and 6.60 lbs. of non-nitrogenous nutrients, the nutritive ratio being 1 : 5.6. The result was an average gain of 0.29 lb. of protein per day (compare pp. 148–150), but a very decided loss of weight, caused probably by a loss of fat.

In two experiments, the animals digested only 0.4 and 0.6 lb. of protein per day and 1,000 lbs. live weight, yet these small quantities sufficed to prevent any loss of flesh, thus confirming the results of the earlier experiments.

The Feeding Standard.—As the direct result of the Weende experiments we find that a ration which supplies about 0.6 lb. of digestible protein and about 7.5 lbs. of digestible non-nitrogenous nutrients per day will suffice to maintain a thousand pound ox without growth or loss of weight.

In all these experiments, however, the temperature of the stall was considerably higher than it is usually practicable to keep it in winter, and as a consequence the demands of the animals for food, particularly for non-nitrogenous nutrients, must have been correspondingly less (compare pp. 231–233). In view of this fact it is probable that the above numbers should be increased somewhat in order to be sure of satisfying the minimum demands of the animals under average conditions. Wolff recommends the following

FEEDING STANDARD.

Digestible protein	0.7	pounds.
" carbhydrates and fat	8.4	"
Nutritive ratio	1:12	
Total dry matter, about	17.5	pounds.

These quantities of digestible matters are amply sufficient in ordinary cases. It is, indeed, probable that the amount of protein might often be decreased slightly without occasioning a loss of flesh, while, on the other hand, exposure to great cold might cause a demand for more carbhydrates.

The number for total dry matter indicates that the fodder should be quite bulky, and may appropriately and profitably consist of straw, with the addition of some hay or of small quantities of nitrogenous bye-fodder, either with or without roots. The quantity of digestible *fat* is of no great importance in the simple maintenance of oxen.

The quantities of the above feeding standard are per day for a thousand pound animal. Lighter animals would require less food of the same quality, and heavier ones more. The variation is not quite in proportion to the weight, however. Small animals require more food than large ones in proportion to their weight, since they expose relatively more surface to radiation and consequently lose heat more rapidly, just as several small hot bodies will cool faster than one large one of equal weight.

Convenience of the Feeding Standard.—Any ration which contains the amounts of total dry matter and of digestible nutrients called for by the standard will serve the desired purpose.

The convenience of possessing such a standard is obvious. On page 375 we have given five rations, any one of which was found to keep the animals in good condition; but these alone would be of little benefit to a farmer who did not have at his disposal exactly the fodders there called for. If he chanced to wish to use hay, or wheat straw, or stover, or not to have rape cake, he would be left entirely in the dark as to how much of these to use, or how to combine them, or what to substitute for them. But with the feeding standard he has simply to calculate, by the aid of a table such as is given in the Appendix, what quantities of the materials at his disposal will give the amounts of the various constituents and the bulk which the standard calls for.

The aid which such a method of calculation gives in comparing the experience of different observers is not easily overestimated; it reduces the heterogenous observations to a comparable form, and to one which shows exactly in what direction the ration is defective, if it is so at all, while a simple statement of the kinds and quantities of fodder used is of only local value. This will appear more strikingly when we come to consider productive feeding.

It may be added in regard to the above standard that it agrees well with the practical experience of German agriculturists.

Exclusive Meal Feeding.—All the experiments hitherto made on the maintenance feeding of cattle have been with various forms of coarse fodder. The plan of wintering stock on corn meal exclusively, which is adopted by Mr. L. W. Miller, has already been alluded to, and presents such a strong contrast to the ordinary system as to merit some consideration.

Mr. Miller's experiments have been made on dry cows, and he states,* as the result of several seasons' experience, that three quarts of good *fine* corn meal per day, fed dry and without other food, are abundantly sufficient to supply the wants of a 900 pound animal.

It is of interest to compare this ration with the feeding standard deduced above. Assuming three quarts of meal to weigh 4.2 lbs., and that the corn meal has the same composition as the average of American maize, viz.:

Water	10.47	per cent.
Ash	1.56	"
Protein	10.96	"
Crude fibre	1.73	"
Nitrogen-free extract	69.69	"
Fat	5.59	"

and assuming also the highest digestion coefficients yet observed for maize, viz.:

Protein	85
Crude fibre	57
Nitrogen-free extract	96
Fat	79

we obtain the following comparison, calculated for a thousand pound animal:

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* In his pamphlet entitled "Meal Feeding and Animal Digestion."

	Standard. Lbs.	4.7 lbs. corn meal. Lbs.
Dry matter	17.5	4.21
Digestible protein	0.7	0.44
" carbhydrates	8.4	3.20
" fat		0.21

A striking contrast is at once manifest. The protein of the corn meal ration, though falling considerably below the amount called for by the standard, is not essentially less than in some of the Weende experiments (p. 375), but the quantity of non-nitrogenous nutrients is very much smaller in the meal ration, and the same is true of the total dry matter.

Mr. Miller and others who have practised his system, state that the animals do not appear to lose flesh on it, and that animals wintered in this way take on flesh when turned out to grass in the spring more readily than after hay-feeding. Though no weighings are given to substantiate these statements, it appears unlikely that any great deterioration in the condition of the animals would have escaped notice. Apparently, we must admit that a ration of three quarts of corn meal is at least nearly sufficient for maintenance.

In accounting for the sufficiency of a ration falling so much below what other experiments have shown to be necessary, several facts must be taken account of.

In the first place, Mr. Miller's rules direct that the stables be kept "warm and comfortable." As already noted, the quantity of digestible protein calculated to be present in the corn-meal is about the same as that digested in the Weende experiments, which were also made in warm stables. Doubtless some saving of protein and a considerable economy of carbhydrates and fat can be effected in this way.

In the second place, the digestible matters of the corn-meal are accompanied by far less indigestible matter, and consequently require less internal work in their digestion, as explained on page 228. Though we have no means of accurately computing the saving thus affected, it is doubtless considerable.

Still a third point, to which attention has recently been drawn by Salmon,* is the fact stated by Mr. Miller, that cows fed exclusively on meal drink but little water, averaging about five quarts per day and head. Five quarts equal about 10½ pounds, while the amount consumed on an ordinary ration of coarse fodder (estimating, according to Wolff, four pounds of water to one of dry matter) would be not far from 70 pounds. Allowing for the half-pound of water in the corn meal, this shows a difference of 59 pounds per day.

Now we have already learned that an increased consumption of water involves an increase in the amount of matter oxidized in the body, particularly in that of the non-nitrogenous matters. This increase is probably due largely, if not wholly, to the demand thus made on the body for heat to warm the water to the temperature of the body and to evaporate part of it. (Compare pp. 234–237.)

If we assume the extra 59 pounds of water consumed when coarse fodder is used to have a temperature of 32° F. when drunk, then warming this water to the temperature of the body (100° F.) would require 1,016,971 units of heat, an amount producible by the combustion of 0.57 pounds of material of the composition of starch.

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* Country Gentleman, July 11, 1878.

Furthermore, a portion of this water is converted into vapor, thus causing a still greater demand for heat. In Henneberg's experiments on sheep (page 235), about one-half the water drunk was excreted as vapor. If we assume that this proportion is applicable to cattle, and that of the 59 pounds of water about 30 pounds are converted into vapor, it is easy to calculate from the data on page 234 that the production of sufficient heat for this purpose would require the combustion of 4.44 pounds of organic matter of the composition of starch.

If, now, we add to the digestible non-nitrogenous matters of the meal ration the amounts estimated to be saved by the less consumption of water, we obtain the following result:

Present in the corn meal	3.41	pounds.
Warming 59 lbs. of water to temperature of body	0.57	"
Evaporating 30 lbs. of water	4.44	"
Total	8.42	"
Feeding standard	8.40	"

Adding to this the fact that an increased consumption of water augments the protein consumption in the body, we have a plausible explanation of the sufficiency of the apparently insignificant ration of three quarts of meal.

Essentially the same result was reached by Salmon (*loc. cit.*), though from different data. These calculations, of course, are based on somewhat uncertain assumptions regarding the amount of water drunk and the proportion of it which is evaporated, and therefore make no claim to accuracy. The only object of introducing them here is to show that it is not at all impossible that exclusive meal feeding can maintain an animal. The practicability and desirability of this method of feeding are matters to be decided by practical experience, while the question of the sufficiency of such a ration can be finally settled only by exact scientific experiments.

§ 2. SHEEP.

Sheep need relatively more Food than Cattle.—It is to be assumed *a priori* that the quantity of nutriment in the maintenance fodder of sheep must be greater than in that of oxen. A certain quantity of protein is demanded for the growth of wool, and the more active temperament and greater amount of movement of these animals, even in the stall, increases the consumption of the non-nitrogenous nutrients. Moreover, on account of their smaller size, it would seem that the loss of heat by radiation must be relatively greater. Under these circumstances, it might, perhaps, have been expected that the difference between the two would be greater than it has been found to be. That it is not may be explained, however, by their thick coat of wool, which hinders the radiation of heat, and perhaps also the evaporation from the skin, so decreasing the demand for heat-producing materials. It is a well-ascertained fact that goats, for example, under the same circumstances and with the same live-weight, require more fodder than sheep.

Experiments in Weende.—Experiments on the maintenance feeding of sheep have also been made by Henneberg,* in Weende, and in them not only the "sensible" excretions, but also the products of respiration, were accurately determined; so that the effects of the feeding on the fat of the body, as well as on its flesh, could be ascertained.

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* Neue Beiträge, etc., 1871.

The experiments were made on full-grown (four and a half years old) sheep of the coarse-wooled variety of the neighborhood of Göttingen (so-called Leine sheep), weighing per head about 106 lbs. They were fed exclusively on average meadow hay, and consumed it at the rate of almost exactly 26 lbs. per 1,000 lbs. live-weight (shorn weight), an amount corresponding to 21.4 lbs. of dry matter. From this ration 1.32 lbs. of protein and 10.53 lbs. of non-nitrogenous matter (including 0.322 lbs. of fat) were digested. If for the fat be substituted its equivalent in starch, the amount of non-nitrogenous matter becomes 11.38 lbs.

This ration caused a small gain, viz., 0.181 lbs. of protein and 0.299 lbs. of fat per day and 1,000 lbs. live weight. It was accordingly abundantly sufficient to maintain the animals without really fattening them. If the gain of protein and fat be subtracted from the above ration (the fat being reduced to its equivalent amount of starch by multiplying it by 2.5), we shall have the following amounts:

Protein	**1.14**	**pounds.**
Carbhydrates, **Fat,**	**10.65**	**"**
Total dry matter	**26.00**	**"**
Nutritive ratio	**1 : 9.3**	

In reality, however, a greater deduction should be made, at least from the protein, since changes in the amount of this nutrient affect the consumption of protein far more than its gain or loss. It is therefore probable that the above quantities would have been rather more than sufficient to maintain the sheep.

This result agrees well with those obtained by Schulze & Märcker in their experiments on sheep, already referred to on page 152. These experiments were made on the same two sheep which were used in the above experiments by Henneberg, and also on two others of the same breed.

If, following Wolff, we divide the twenty experiments which were made, into two groups, according to the total amount of digestible nutrients, and then subdivide these groups according to the wider or narrower nutritive ratio, we obtain the following averages, each of five experiments, per day and 1,000 lbs. live-weight:

Digested protein. Lbs.	Digested carbhydrates and fat. Lbs.	Total nutrients. Lbs.	Nutritive ratio.	Gain (+) or loss (−) of protein. Lbs.
1.04	9.49	10.53	1 : 9.1	−0 042
1.56	9.54	11.11	1 : 6.1	−0.006
1.11	11.70	12.81	1 : 10.5	+0.124
2.31	12.25	14.56	1 : 5.3	+0.245

Plainly, the third ration gave, on the whole, the most satisfactory results, and it will be seen that it corresponds quite closely with the results of Henneberg's experiments, while the average of the first three does not vary much from it, viz.:

Digestible protein	1.24 pounds.
" carbhydrates and fat	10.24 "
Nutritive ratio	1 : 8.3

It was also found in these experiments that, as in the case of oxen, a too narrow nutritive ratio is to be avoided in simple feeding for maintenance.

Experiments have also been made by Wolff,* in Hohenheim, upon the feeding of sheep. Animals of three different breeds were used, viz., Merinos, Southdowns, and the so-called Würthemberg bastard breed (grade Merinos), and each received two different rations, viz., per 1,000 lbs., shorn weight:

	Digestible protein. Lbs.	Digestible carbhydrates and fat. Lbs.	Total. Lbs.	Nutritive ratio.
I.............	1.37	8.92	10.29	1 : 6.1
II............	1.23	9.93	11.15	1 : 8.1

These quantities agree well with those used in Weende, except that the quantity of carbhydrates, and consequently the total amount of nutritive matters, is somewhat less, a fact which explains the slight decrease of weight which the animals suffered, especially when the daily growth of wool was taken into account.

The loss of weight was somewhat greater with the so-called "electoral" sheep (Merinos) than with the Southdowns or the natives. Sheep of the fine-wooled breeds are mostly smaller and of a more delicate build than those of the coarse-wooled races, and consequently demand a somewhat greater amount of nutriment for the same live-weight than the latter.

The general result of the researches hitherto made is that mature sheep which are kept solely for the production of wool may be kept constantly in good condition by rations corresponding to the following feeding-standards:

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* Landw. Jahrbücher, I., 533.

FEEDING STANDARDS—PER 1,000 POUNDS LIVE-WEIGHT, PER DAY.

	Protein. Lbs.	Carbhydrates and fat. Lbs.	Total dry matter. Lbs.	Nutritive ratio.
Coarse-wooled breeds..	1.2	10.8	20–23	1 : 9
Fine-wooled " ..	1.5	12.0	20–23	1 : 8

The daily growth of washed wool amounts to from 0.12 to 0.20 lb., according to breed and individual peculiarities. All the above figures are for 1,000 lbs. live-weight, *exclusive of the wool* (shorn weight), but it is probable that they can be applied directly to unsheared animals, without any considerable error; at any rate, the failure would be on the safe side, and we should have the assurance that the calculated quantity of food was abundantly supplied.

Production of Wool.—Thus far we have not specially regarded the growth of the wool in considering the proper ration for sheep. The wool, however, may be the principal object in view, and demands a more detailed consideration.

The feeding has a decided influence upon the production of wool, but only within certain limits. Full-grown animals do not yield noticeably more wool under the influence of a fattening fodder than of one which suffices to keep them in good condition without causing any essential increase of their real weight (exclusive of wool).

This is shown by experiments made in Weende * on Negretti sheep, which, on a maintenance ration, produced in the average of seven experiments, 0.141 lb. of wool per 1,000 lbs. live-weight, per day, equal to 0.273 per cent. of the shorn weight, while as the average of fourteen experiments with a fattening ration, they produced the same quantity of wool, 0.141 lb. per 1,000 lbs. live-weight, per day, or 0.286 per cent. of their shorn weight.

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* Jour. f. Landw., 1858, p. 362; 1860, p. 1; 1861, p. 63.

An equally decided result was yielded by experiments in Hohenheim,* with lambs. A very rich ration, consisting of hay and an abundance of oats, caused the live weight to increase in the course of nine months from 55.9 lbs. to 101.8 lbs. per head, while a ration consisting exclusively of meadow hay, at first of excellent and later of average quality, caused the weight to increase from 55.0 lbs. to only 79.5 lbs. The richly-fed animals were, at the close of the experiment, well fattened, while those fed with hay were simply in good condition, but the quantity of pure wool produced in the two cases was almost identical. It was noticeable in these trials that the wool of the grain-fed animals remained very clean and white in appearance, while that of the hay-fed ones had the usual dirty appearance, and even when washed appeared somewhat gray in comparison with the other.

The following were the quantities of wool obtained per head in the two cases:

Fodder.	Unwashed wool. Lbs.	Washed wool. Lbs.	Wool with fat removed. Lbs.
Hay..................	5.92	3.54	2.46
Hay and Grain.........	4.79	3.25	2.39

The quantities of pure wool were as good as identical.

If, however, the fodder of sheep is insufficient for their maintenance in good condition, the case becomes different. From the numerous experiments in Weende, the conclusion could be drawn that, although the growth of the wool did not always suffer when the weight of the animals decreased *somewhat*, such a diminution was unavoidable if the decrease passed a certain limit. In one such case, for example, the daily production of wool amounted to only 0.237 per cent. of the shorn weight against 0.292–0.306 per cent. with better food.

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* Landw. Jahrbücher, II., 221.

It was also found that rations which did not fully suffice to maintain the animals unaltered, produced less ill effect on the growth of the wool when they were comparatively rich in protein, and that, other things being equal, the ration which is the richer in protein is to be preferred. The limits within which this is applicable in maintenance feeding, have been already indicated.

On the other hand, there appears to be a limit below which a decrease in the fodder does not decrease the growth of the wool.

The most wool seems to be produced when the animals are thoroughly well fed, but not fattened. If the daily ration be increased beyond what is necessary for this, no effect is produced on the growth of wool, but if the ration falls much below this minimum, the amount of wool also falls, to a certain extent. The growth of the wool, however, is not directly dependent on the food, and will continue even in the absence of it or when it is small in amount, and is only affected by it within the limits just mentioned.

This is well shown by some Hohenheim observations. The sheep, at the beginning of the experiments, were in a well-fed condition, and were divided into five lots of six head each. Two lots (III. and IV.) received a rather nitrogenous ration, consisting of hay and beans, in such quantity as just to maintain their weight and condition. Two other lots (I. and II.) received a less quantity of a ration poorer in protein, so that their average weight per head decreased in 121 days from 101.4 lbs. to 97 lbs., while a fifth lot (V.) received still less of a still poorer fodder, and decreased in average weight per head from 101.1 lbs. to 89.3 lbs. Lots I. and II. were fed with straw and mangolds, and lot V. with about two-thirds hay and one-third oat-straw.

The amount of wool produced by each lot was the following:

Lot.	Washed wool. Lbs.	Washed wool in per cent. of shorn weight.
I.	8.5	26.5
II.	7.0	
III.	9.0	31.9
IV.	11.0	
V.	8.1	27.3

Lots III. and IV., in which the original well-fed condition was preserved, produced the most wool, and judging from the experiments already described, it is probable that, had the fodder been increased so as to fatten the animals, no greater growth of wool would have taken place.

In lots I. and II. the poorer fodder had as its effect a lessened growth of wool, while in lot V., in which the fodder was still poorer, the growth of wool continued, but at the expense of the body, which decreased decidedly in weight.

To sum up the whole matter, the growth of wool is a process which goes on with tolerable uniformity as long as the animal lives, and whose rapidity is determined by breed and individual peculiarities, and only secondarily and within rather narrow limits by the food. All that is necessary or profitable in the way of feeding is to keep the sheep in good condition; if they lose weight seriously, the yield of wool suffers to some extent, though the animals suffer more, while, on the other hand, fattening is simply an unnecessary use of fodder so long as wool is the sole object, since it does not increase the amount of the latter.

The feeding standards already given may be safely taken as a guide, since they appear to be abundantly sufficient to maintain a good, well-fed condition. It has, however, been generally found that when the fodder consists largely of roots and straw, more digestible protein is required than when it is composed mostly of hay. We have already learned that a large part of the "crude protein" of roots is really not protein at all, and we have here, perhaps, an indication of the less nutritive value of the non-protein.

CHAPTER III.

FATTENING.

§ 1. CATTLE.

THE fattening of animals has for its object chiefly the formation and deposition of fat in the body, and to a far less degree an increase in the amount of flesh. According to the researches of Lawes and Gilbert, in England (p. 9), the amount of fat formed is about ten times that of the protein deposited in the body, and more than twice that of the fresh flesh. The experiments of Henneberg, Kern & Wattenberg (p. 178) on the fattening of sheep also showed a large formation of fat and a small one of flesh.

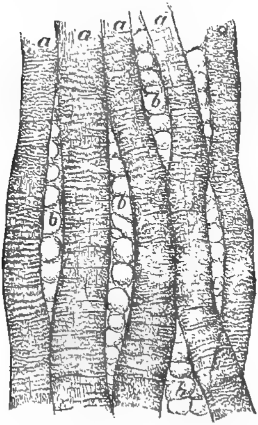

FIG. 7.—Fat-Cells in Muscle. (Settegast.)

In very fat animals the fat is not only deposited in the fat-tissues proper, but is found between the fibres of the muscles themselves, as illustrated by Fig. 7, where *a* represents the muscular fibres, and *b* the fat-cells. The tenderness and juiciness, as well as the nutritive value of the resulting meat is thus considerably increased.

The general laws of the formation of flesh and fat have already been treated of at considerable length in Part

I., but the most important points may be repeated here in their application to practical purposes. It will be convenient to take them up in connection with the fattening of cattle, though the same general laws are of course applicable to all domestic animals.

Experiments in Weende.—The few experiments on the fattening of cattle which have as yet been executed were made at the Weende Experiment Station in the years 1859, 1860, and 1865.* In these experiments the digestibility of the fodder, as well as the gain of flesh, was determined. The experiments in 1859 and 1860 extended over a considerable time, while those in 1865 were of so short duration as to render the results of less value. The following table contains the more important results of the experiments, calculated per day and 1,000 pounds live-weight:

Date.	Protein digested. Lbs.	Carbhydrates and fat digested. Lbs.	Nutritive ratio. 1:	Length of experiment. Days.	GAIN PER DAY.	
					Live-weight. Lbs.	Flesh. Lbs.
1859..........	1.56	8.50	5.5	56½	1.36	0.68
	1.50	8.38	5.6	56½	1.43	−0.57
1860..........	1.45	11.10	7.6	71	1.83	0.89
	1.55	12.70	8.2	45	1.30	1.44
1865..........	1.76	8.90	5.1	17 †	0.42	1.56
	1.82	7.68	4.2	19 †	1.45	1.53
	1.73	8.62	5.0	17 †	0.21	2.22

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* "Beiträge zur Fütterung der Wiederkäuer," Heft 2, p. 276, and "Neue Beiträge," p. 314.

† Exclusive of the preliminary feeding.

No extended conclusions can be drawn from so few experiments. The gain of live-weight was comparatively slow in all these trials, and the rations were evidently not sufficient to cause a rapid fattening. In several cases it will be observed that the gain of fresh flesh is greater than the increase of live-weight. This may indicate a loss of some other substance (probably water) from the body, or may be due to inaccuracies in the determination of the true live-weight.

In a general way we may state, as the result of these trials, that a slow fattening may be effected by a ration containing per day and 1,000 pounds live-weight

Digestible protein........................	1.5– 2.0 pounds.
Digestible carbhydrates and fat...........	8.0–13.0 "

It will be noticed that the quantity of non-nitrogenous nutrients does not vary greatly from that needed for maintenance, while the amount of protein is considerably greater. We have here another example of a gain of flesh and fat produced by the addition of protein to a ration poor in that substance. (Compare p. 148 *et seq.*)

Fat from Carbhydrates.—In case a more rapid fattening is desired, it is plain that more food must be given; but whether the increase shall consist of protein or of non-nitrogenous nutrients, or both, can be determined at present only by theoretical considerations.

Here the question of the formation of fat from carbhydrates comes in. We have seen that many facts seem to indicate the possibility of such a formation, and the query naturally arises, whether, since the chief object of fattening is a formation of fat, an increase of the carbhydrates and fat of the fodder will not effect the desired object, more especially since the protein consumption is thereby diminished.

There is no doubt that, with a given amount of protein in the ration, the addition of non-nitrogenous nutrients will effect a gain of both flesh and fat; but several considerations forbid the use of too large quantities of carbhydrates and fat.

In the first place, if the fodder contains too large a proportion of non-nitrogenous matter, the animal will not receive enough protein to cause any gain of flesh or to supply material for the formation of new fat-cells.

In the second place, experiments on sheep have shown that the fattening of these animals is much more rapid and certain on a ration containing a liberal proportion of protein, and there is no evident reason why the same thing should not be true of cattle. The formation of fat from carbhydrates cannot be regarded as proved. Still less have we any knowledge of the conditions under which it takes place, and consequently we must for the present regard them as only indirect aids in fattening.

Feeding Standard.—The considerations just presented render it manifest that the feeding standard for fattening cattle must vary considerably under different circumstances.

For slow fattening we might use such a ration as that given on page 394, viz.:

Total dry matter	18–20	pounds.
Digestible protein	2	"
" carbhydrates and fat	13	"
Nutritive ratio	1 : 6.5	

If a more rapid fattening is desired, two ways of attaining the object present themselves.

By increasing the non-nitrogenous matters of the above ration to perhaps 16 pounds, it is probable that a saving of protein and a somewhat greater gain of fat might be effected. It is to be considered, however, that by making the nutritive ratio so wide (1 : 8) we incur the risk of imperfect digestion of the protein. (Compare page 280 *et seq.*)

Probably the nutritive ratio 1 : 6.5 is as wide as it is advisable to use in most cases, and a more rapid fattening could then be caused by simply increasing the total quantity of nutrients per day, leaving the proportions of protein and non-nitrogenous matters unchanged, but using, if necessary, more concentrated feeding-stuffs in order to avoid too bulky a fodder. The quantities of nutrients recommended in the following paragraphs and in the table of feeding standards in the Appendix are calculated for rapid fattening. As already stated, they are largely derived from theoretical considerations, and hence are to be taken only as a general guide.

Preliminary Feeding.—Cattle that are much reduced in flesh and fat cannot be at once quickly fattened. For this purpose they must first be brought into a well-nourished condition. It is impossible to render the animal body rich in flesh and fat unless it already contains a certain not too small amount of organized and circulatory protein, by means of which only it is capable of digesting, resorbing, and storing up protein and fat.

In order to bring about such a condition, the cattle may, for example, be fed for two or three weeks chiefly on clover hay, with a moderate addition of grain and oil cake, brewers' grains, malt sprouts, beans, or some similar highly nitrogenous bye-fodder, so that the ration contains, per 1,000 lbs. live-weight, about 2.5 lbs. of protein and 12.5 lbs. of non-nitrogenous nutrients, making the nutritive ratio quite narrow (1 : 5).

The effect of such a fodder, as will be gathered from the chapter on the formation of flesh, is to increase the stock of circulatory protein in the body (and, of course, the rate of its decomposition also) without causing any essential gain of flesh. A slight deposition of fat might take place in the tissues, but, with such a narrow nutritive ratio, most of it would probably be oxidized.

First Period.—After this condition of affairs has been well established by the preliminary feeding, the real fattening begins.

In the first period the quantity of the non-nitrogenous nutrients is increased to about 16.25 lbs., thus considerably widening the nutritive ratio (1 : 6.5). The effect is that the rate of decomposition of the circulatory protein is decreased and a part of the albuminoids of the food, instead of being rapidly oxidized, is converted into the stable "organized protein." At the same time, much of the fat coming from the decomposition of the protein, as well as that contained in the food, is protected from oxidation and deposited in the body.

Second Period.—After considerable fat has been deposited in the animal (after about a third, perhaps, of the period of fattening has passed) it is advisable to gradually increase the quantity of protein in the food to about 3.0 lbs. per day, thus narrowing the nutritive ratio again to 1 : 5.5. By thus increasing the proportion of protein, a more rapid fattening may be attained, while the fat already deposited in the body will prevent any great increase of the protein consumption in the body. (Compare page 133.)

Fodder of the composition here indicated is to be regarded as the real fattening fodder, and to be continued unaltered for a considerable time.

Third Period.—In practice it is often customary, toward the end of the fattening, to again give the animals a fodder somewhat poorer in protein; for example, replacing the oil cake or other nitrogenous bye-fodder by grain. An essential advantage may be gained in this way, if the fodder is thus increased in palatability, as may often be the case, or if the total quantity of digestible nutrients is increased. It is likewise possible that a wider nutritive ratio toward the close of the fattening may cause more protein to be converted into the organized form, but it would seem hardly advisable to make the ratio wider than 1 : 6.

Addition of Oil to Fodder.—Increasing artificially the amount of fat in the fodder by the direct addition of pure fat, *e. g.*, linseed oil, to the amount of 0.5—1.0 lb. for oxen, and 30—40 grms. for hogs per day and head, has often been found to have a good effect in increasing the live-weight of the animals, more especially when the nutritive ratio was narrow. By its means, as we have learned, the gain both of flesh and fat is favored. Such an addition would be in place in the second period of fattening when the fodder is most concentrated.

This practice, however, demands great care and judgment, and does not seem as yet to have found favor in practice; the purer fats occurring in trade are too expensive, and a favorable result is by no means assured. Indeed, it is not seldom the case that injurious consequences to the appetite and digestion, especially of the ruminants, may result from the use of pure fats or oils, especially if the quantity is at all large or the use of it is continued too long.

Notwithstanding this, however, the amount of fat in the rations of fattening animals is certainly a point worthy of attention, and it should be our endeavor to increase it as much as can safely be done, especially when the nutritive ratio is narrow. This can be accomplished without special expense by the use of oil cake, cotton-seed cake, palm-nut cake, or sometimes by the direct use of flaxseed.

Preparation of Fodder.—In rapid fattening it is especially important to induce the animals to eat as large a quantity as possible of nutritious and easily-digestible fodder by making the latter as palatable as may be. For this purpose the fodder should be properly prepared, and a suitable addition of salt aids in securing the same end. By thus properly preparing the fodder so as to increase its palatability, and consequently the amount eaten, great advantages may often be gained, even though, as we have seen, neither the digestibility nor the real nutritive value of a given quantity are thereby increased.

Fattening fodder, on account of its concentrated nature, requires the addition of considerable salt, especially when large quantities of potatoes or roots are used. Care must be taken, however, not to increase the amount of salt beyond what is necessary, since both the salt itself and the greater consumption of water which it causes increase the destruction of protein and fat in the body (pp. 135 and 236), and thus occasion a waste of the most costly ingredient of the fodder and hinder the gain of flesh.

For the same reason a too watery fodder must be avoided, if the best results are to be obtained. The proportion of water to dry matter of the fodder should not exceed four or five to one for cattle, and two or three to one for sheep.

§ 2. SHEEP.

Proportion of Protein.—All the experiments on sheep hitherto made agree in showing that with these animals the rapidity of fattening is chiefly dependent on the supply of protein. As already stated in another connection, numerous experiments on the fattening of sheep have been carried out at the various German experiment stations. In the following table, by Wolff, already given on page 178, fifty-nine of these experiments are divided into four groups, according to the amount of digestible protein contained in the fodder. The average weight of the animals was about ninety pounds.

No. of Experiments.	Digested per Day and Head. Average.			Nutritive ratio.	Increase of live-weight per day and head. Lbs.	Dressed weight in per cent. of live-weight.
	Albuminoids. Lbs.	Non-nitrogenous nutrients. Lbs.	Total nutrients. Lbs.			
7..............	0.220	1.648	1.868	1 : 7.49	0.111	48.0
13..............	0.268	1.557	1.825	1 : 5.81	0.158	51.9
20	0.329	1.588	1.917	1 : 4.70	0.189	53.5
19.	0.384	1.538	1.922	1 : 4.01	0.206	54.9

These results show plainly the importance of a liberal supply of protein in the fodder of fattening sheep. While the total amount of nutrients digested was nearly the same in all the groups, those in which the proportion of protein was greatest show not only a more rapid gain but also a larger proportion of dressed weight to live weight.

Feeding Standard.—As in the case of cattle, it is impossible to give any single standard suited to all cases. Any one of the rations of the foregoing table might serve as a feeding standard, the fattening being more rapid, and at the same time more expensive, the greater the proportion of protein.

Sheep can consume, relatively, somewhat more fodder (total dry matter) than cattle, and can also bear more concentrated food. We may perhaps put the maximum amount of digestible nutrients at 18 pounds per day and 1,000 pounds live-weight for the latter, and at about 20—21 pounds for the former.

In view of the importance of a due proportion of protein in the fattening of sheep, it seems probable that the smallest amount given in the preceding table, viz., 0.22 lb. per day and head, or about 2.5 lbs. per day and 1,000 lbs. live-weight, is the least quantity with which a good result can be secured in most cases. This amount, with 17.5 lbs. of non-nitrogenous nutrients, gives 20 lbs. of total digestible matters, and a nutritive ratio of 1 : 7.

Such a ration may be considered as approximating to the minimum ration for fattening purposes. By increasing the digestible protein to 4.2 lbs. and decreasing the non-nitrogenous nutrients to 16.8 lbs., we get a ration having a nutritive ratio of 1 : 4, and containing 21 lbs. of total digestible matters. This is a very concentrated ration, and its narrow nutritive ratio and large amount of protein must cause a very considerable protein consumption. An increase of the amount of protein beyond this point will hardly ever be advisable, since in that case the non-nitrogenous nutrients must be decreased still more, not leaving enough to protect the protein and fat of the food from unnecessary oxidation.

Between the two limits just indicated, the choice of a feeding standard will be determined by the special conditions of each case. As in the case of cattle, a preliminary feeding may often be necessary, and a rather wide nutritive ratio is to be recommended in the earlier stages of fattening, which may subsequently be gradually narrowed to such an extent as may prove profitable. If the sheep are in a well-fed condition at first, the preliminary feeding may be omitted and the first period somewhat shortened, the second being correspondingly lengthened.

Quantity of Water.—A good fattening fodder for sheep must not be too watery; hence, large quantities of brewer's or distiller's grains, or even of roots, are of far less benefit to these animals than to cattle. On the other hand, the use of potatoes allows a more favorable ratio (about 1 : 2—3) between water and total dry matter to be obtained. The best results are generally reached, however, when suitable kinds of grain or its bye-products are used, along with good hay.

Best Age for Fattening.—Sheep can be fattened most rapidly at an age of from one and one-half to three years. It is true that, with rich fodder, the same quantity of nutrients will cause as great or even a greater increase of live-weight in yearlings as in somewhat older animals, a fact which is true of all young animals in rapid growth. Such animals, however, are usually not as desirable for the butcher, since the flesh remains watery, and the dressed weight, and especially the quantity of fat, is generally small. Only when the lambs are taken as young as possible and fed very highly is it possible to attain, at great expense, the same result which may be reached in a far shorter time, often less than three months, with older animals.

The result of fattening is always most favorable, both in quality and quantity, with tolerably mature animals. On the other hand, if the animals are allowed to become too old and the fattening is begun after they have reached the age of perhaps four years, a large deposition of fat, it is true, takes place, but the flesh has far less palatability than that of younger animals.

Effect of Shearing.—It is a noteworthy fact, and one which has been confirmed by numerous experiments, that fattening sheep after being shorn increase in live-weight much more rapidly than immediately before shearing. It has been observed, moreover, in some cases, that while before shearing the more nitrogenous ration produced a decidedly greater effect than one poorer in protein, the difference between the two almost disappeared after shearing, so far as the increase in live-weight was affected.

The more rapid increase in weight after shearing is usually explained very simply by the fact that the appetite of the animals is thereby almost always increased, so that more fodder is eaten. In one experiment in Weende, however, the amount of fodder consumed remained the same, and yet the gain in weight was greater after than before shearing. In this experiment it was observed that much less water was drunk after shearing, doubtless in consequence of decreased perspiration, a fact which would favor and may explain an increased gain (compare pp. 135, 198, and 234). A similar decrease in the amount of water drunk was observed in experiments in Proskau; the gain of flesh, however, was not increased, but on the contrary the protein consumption in the body increased some five per cent., and the gain of flesh decreased correspondingly. This, of course, does not exclude the possibility of an increased gain of fat, but it renders it improbable. The digestibility of the fodder was exactly the same before and after shearing.

On the whole, then, we must conclude that the increased appetite of the animals resulting from shearing is, so far as we can now see, the chief if not the only cause of the more rapid fattening.

§ 3. SWINE.

Quantity of Fodder.—The amount of fodder consumed by swine, in comparison with other animals, is very large. When tolerably full-grown swine are fattened, they consume at first a great quantity of fodder, amounting, per 1,000 lbs. live-weight, to upward of 40 lbs. of dry matter per day, and they increase in weight with corresponding rapidity.

As they grow fatter, however, the consumption diminishes continually, and finally becomes hardly greater than that of fattening cattle or sheep. This fact is shown still more strikingly when, as is usually the case, the swine receive full fattening fodder as soon as they are weaned, and reach in the first year a weight of some 300 lbs. per head. Under these circumstances, when the fodder is a suitable one and the animals belong to a breed capable of easy fattening, an increase of 100 lbs. in the live-weight may be obtained by about 400 lbs. of dry matter in the fodder, on the average, or by 300—400 lbs. in the first months and 400—500 lbs. in the later months—a fact which has been exemplified by numerous experiments in Weidlitz, Kuschen, Pommritz, Hohenheim, and elsewhere. Older animals, however, seem to need more fodder for an equal production. As much as 500—600 lbs. of dry matter appears to be necessary to produce an increase of 100 lbs. in the live-weight of mature swine.

Feeding Standards.—The fattening of mature swine may be, for convenience, divided into three periods, as is done in the table of feeding standards in the Appendix; but it will be noticed that the nutritive ratio is gradually made wider with the advance of the fattening, while the total quantity both of dry matter and of real nutrients is decreased in accordance with the facts stated in the previous paragraph. This widening of the nutritive ratio has shown itself advantageous, especially toward the end of the fattening, in giving the fat a firmer consistency and better quality, while the animals are not as liable to disease as when they receive more highly nitrogenous fodder.

The plan commonly pursued with swine is to feed a rich fodder from the first and thus carry on growth and fattening together, and most experiments on the fattening of swine have been made in this way. A consideration of the results of these experiments will be found in Chapter VI.

Mineral Matters.—It contributes essentially to maintaining the health of the animals to add daily a small quantity ($\frac{1}{4}$—$\frac{1}{2}$ oz. per head) of lixiviated chalk, or even of leached wood-ashes, to the fodder. Such an addition to the food of young fattening swine should never be omitted, since their fodder is generally poor in lime, though rich in phosphoric acid. (Compare Chapter VI.)

Choice of Fodder.—The quantities of nutrients and the nutritive ratio called for by the feeding standards may, of course, be supplied by combinations of very various feeding-stuffs. It is the part of the practical farmer to make the most suitable and profitable choice among these. But, although this work does not undertake to supply the lack of experience, a few points may be mentioned; as, for example, that it has been the experience of German investigators that barley, maize, and peas (the latter mixed with steamed potatoes), have produced excellent results, while oats and bran, when fed in large quantities, have been much less satisfactory. They have also found that feeding-stuffs which of themselves are less suitable for swine, can be made to produce better results by a moderate addition of sour milk, or even of whey.

The bye-products of the manufacture of cheese deserve attention for improving the rations of swine, and the easily digestible flesh-meal (p. 349) appears to exert an equally favorable influence, and is especially to be recommended, when obtainable, as an addition to rations poor in protein. Fish-scrap would probably serve the same purpose equally well, and has, moreover, the advantage over flesh-meal that it contains a greater proportion of ash ingredients and is particularly rich in phosphate of lime.

CHAPTER IV.

FEEDING WORKING ANIMALS.

§ 1. INTRODUCTORY.

IN regard to the amounts of the several nutrients needed in the fodder of working animals, we have as yet, unfortunately, scarcely any exact experiments, and can therefore, for the present, form an opinion only from the general laws of animal nutrition or on the basis of practical experience.

Working Animals must be well fed.—We know that the animal body needs, first of all, a muscular system which is developed and inured to work, to render it capable of hard and continued labor, and also that the body must be tolerably rich in both organized and circulatory protein, in order to furnish materials for the processes explained in the chapter on the production of work. In order to reach and maintain this condition more nutriment and a narrower nutritive ratio are necessary than simply for the maintenance of resting animals.

Need of Protein.—During work, as we have learned, no more protein is destroyed than under the same circumstances without work. At the same time, the protein is an essential factor in the production of work, and only when its amount is rendered sufficiently large by a correspondingly large supply of it in the food is the body capable of continued and severe exertion.

Importance of Fat.—While the decomposition of protein is essentially regulated by the kind and quantity of food and the condition of the body, the oxidation of the fat, on the contrary, is increased as a direct consequence of muscular exertion.

To prevent the consumption of the body-fat and an emaciation of the animals, is the function of the fat and carbhydrates—the non-nitrogenous nutrients—of the food (see pp. 187 and 191). Fat, however, is the most concentrated of all these nutrients, and it must, therefore, be of advantage to include in the fodder of working animals a certain quantity of fat. That this quantity must not be too great has been already insisted on. In any case it is clear that working animals must receive a larger quantity of non-nitrogenous as well as of nitrogenous nutrients than is necessary in rest, and must receive more, the greater the amount of work which it is desired to obtain from them in a given time.

§ 2. WORKING OXEN.

Feeding Standard.—Working oxen can perform a small amount of labor with very little more nutriment than suffices for their maintenance at rest, but if they are to be even moderately worked, the amount of nutritive matter must be largely increased, so as to amount, per 1,000 lbs. live-weight, to about 1.6 lb. of digestible protein, and at least 12 lbs. of digestible non-nitrogenous nutrients per day; the nutritive ratio is then 1 : 7.5. Such a ration would correspond to feeding with hay of average quality, with the addition of small quantities of a nitrogenous bye-fodder, or to a mixture of clover-hay and straw, or it might also be prepared chiefly from straw and roots, with a suitable nitrogenous bye-fodder. The total organic matter may amount to about 24 lbs.

If very heavy work is to be done continuously, the quantity of digestible nutrients should be still further increased, the protein to as much as 2.4 lbs., and the non-nitrogenous matter to 14.5 lbs. (nutritive ratio, 1 : 6).

Fat not important.—The amount of fat in the rations of working oxen scarcely comes into consideration, since these animals, although they draw heavy loads, perform their work slowly, and hence have less need of concentrated respiratory materials. Moreover, they have capacious stomachs in which large quantities of carbhydrates can be contained, while the comparative slowness with which the latter move through the digestive apparatus permits large quantities of them to be digested and resorbed.

In the ordinary feed of working oxen the fat scarcely amounts to 0.3 lb. per day; in the ration for heavily worked animals it may sometimes be advisable to increase it somewhat by the use of a bye-fodder which is at the same time rich in fat and in protein (such as oil cake or cotton-seed cake), so that the total amount of digestible fat may reach, perhaps, 0.5 lb. per day.

§ 3. Horses.

Fodder determined by Amount of Work.—The food of the horse is in general very constant as regards its materials, consisting chiefly of oats and hay, with sometimes more or less straw, but the relative quantities of these ingredients and the total quantity of fodder vary more than with almost any other animal, and are almost wholly determined by the amount of work performed.

Neither the temperament nor the constitution of the horse fit it to consume an abundant fodder when not performing regular work, while, on the other hand, as the amount of work demanded increases, the intensity of the feeding must also be increased, until the ration may finally come to consist almost wholly of oats.

The Hohenheim Experiments.—The only experiments on the feeding of working horses are those recently executed at Hohenheim by Wolff and others. These experiments were made primarily to test the digestibility of various feeding-stuffs; but some information may be gained from them as to the amount of nutriment needed by the horse. The experiments were all made on the same animal, and consequently the results are strictly applicable only to this animal, but, at the same time, it is to be anticipated that the general conclusions drawn from them will be confirmed by subsequent investigation.

Quantity of Fodder.—In these experiments it was found that a horse weighing 1,100—1,200 lbs., when fed exclusively on hay, easily ate 22 lbs. per day, but that 27½ lbs. appeared to be the maximum amount which he could consume. These amounts contained respectively 19.4 lbs. and 24.0 lbs. of dry matter. In later experiments, in which grain was fed, the maximum amount of dry matter consumed per day was 25 lbs.

It would thus appear that 20—25 lbs. is about the limit for the amount of total dry matter in the ration of a horse weighing 1,200 lbs. It will be seen at once that, as was to be expected, this quantity is much less than is consumed by ruminating animals. This fact was strikingly shown in some experiments in which the same hay was fed to sheep for comparison. The latter animals consumed, per 1,000 lbs. live-weight, 31.25 lbs. of hay, containing 27.2 lbs. of dry matter, and could apparently have eaten more.

Digestible Nutrients.—The following table* contains a summary of the more important Hohenheim experiments, showing the amount of nutrients digested per day and their effect on the live-weight. The amount of work performed is given in kilogramme-metres; an ordinary day's work is estimated at about 1,500,000 kilogramme-metres.

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* Wolff: Landw. Jahrbücher, VIII., I. Supplement, p. 113.

LIGHT WORK.

Work per day. Kilogr.-metres.	Length of experiment. Days.	Live-weight. Lbs.	Dry fodder per day. Lbs.	DIGESTED PER DAY.				Nutritive ratio 1 :	Change in live-weight per day. Lbs.
				Protein. Lbs.	Fat. Lbs.	Carbhydrates. Lbs.	Total nutrients. Lbs.		
475,000	62	1,078	18.6	1.3	0.4	7.9	9.6	6.9	−1.0
475,000	28	1,157	24.0	1.8	0.4	10.5	12.7	6.4	0
600,000	14	1,197	18.5	1.4	0.1	7.2	8.7	5.6	−2.0
600,000	14	1,151	16.7	2.0	0.1	6.7	8.8	3.4	−3.3
600,000	56	1,093	21.3	3.1	0.1	8.8	12.0	3.0	0
600,000	25	1,034	24.7	4.0	0.1	10.9	15.0	2.8	+1.1
600,000	30	1,065	25.0	3.3	0.2	12.3	15.8	3.9	+1.0
600,000	39	1,146	24.9	2.2	0.4	13.4	16.0	6.5	+2.1

ORDINARY WORK.

1,108,000	40	1,120	24.0	1.8	0.4	10.8	13.0	6.7	−1.4
1,800,000	30	1,010	21.4	3.0	0.1	8.7	11.8	3.0	−2.8

The experiments in which only light work was performed are tolerably numerous, and agree well with each other, although it must be borne in mind that they were executed at different times, and that the bodily condition of the animal varied considerably. As their general result, we may say that a ration containing 12 to 13 lbs. of digestible nutrients, and having a nutritive ratio of about 1 : 6.5, is sufficient for a horse weighing about 1,200 pounds and performing only light work. All the experiments in which the total quantity of digested matter falls below this amount show a loss of weight, while those in which it is exceeded show a gain. It would seem, from the fifth experiment, that the nutritive ratio may safely be made considerably narrower than that given above; but such a change would only increase the cost of the feeding without producing an essentially better result.

The few experiments in which the amount of work was increased to an ordinary day's work, or somewhat beyond, only show the insufficiency of the above-mentioned ration, but give us no information as to the amount by which it should be increased. It is noticeable that in these experiments the loss of weight was less on a wide nutritive ratio; at the same time, however, the total amount of digested matters was somewhat greater, though that of the protein was much less.

Feeding Standards.—The following table contains the above feeding standard, calculated per 1,000 pounds live-weight, and also the standards recommended by Wolff for ordinary and for heavy work:

FEEDING STANDARDS.—HORSES.

Per Day and 1,000 Pounds Live-Weight.

	Total dry matter. Lbs.	DIGESTIBLE.			Nutritive ratio, 1 :
		Protein. Lbs.	Carbhydrates. Lbs.	Fat. Lbs.	
For light work....	21.0	1.5	9.1	0.3	6.5
" ordinary work.	22.5	1.8	11.2	0.6	7.0
" heavy work...	25.5	2.8	13.4	0.8	5.5

The desirability of the more highly nitrogenous diet here recommended for heavily worked horses is indicated by practical experience.

Importance of Fat.—What has been said in regard to the importance of fat in the food of working animals is especially applicable to the horse, and it can hardly be a matter of chance that the oat, which is regarded as the natural food of the horse, is distinguished from other cereals by its richness in fat. This fact must be borne in mind in attempting to replace the latter, either partially or wholly, by other feeding-stuffs.

The carbhydrates can, it is true, take the place of fat to a certain extent; but it may be questioned whether they always suffice, and in any case the fat of the food must add to the supply of respiratory materials, and thus be of value, especially in severe work.

Kinds of Feeding-stuffs.—The feed of the horse ordinarily consists, as already said, of hay and oats, though various attempts have been made, with more or less success, to replace the latter by other feeding-stuffs.

Exclusive hay-feeding is still less adapted to horses than to ruminants, since, as we have seen, the amount which the former can eat is comparatively small, amounting to barely 23 pounds per day and 1,000 pounds live-weight, and containing 20 pounds of dry matter. Hence the necessity of adding some concentrated food like oats to the hay becomes self-evident, and is rendered even more so when we consider that the digestive power of the horse for certain ingredients of coarse fodder, notably crude fibre, falls below that of ruminants.

CHAPTER V.

PRODUCTION OF MILK.

§ 1. THE MILK-GLANDS AND THEIR FUNCTIONS.

Milk is not simply a Secretion.—In order to an understanding of the influence of the fodder upon the quantity and quality of the milk, it is important to gain a clear conception of the mode of formation of the latter.

The milk is not simply secreted from the blood, like the urine in the kidneys, or the digestive juices in the stomach and intestines, but is formed in the milk-glands from the cells of the gland itself; it is the liquefied organ. This is shown even by the composition of its ash, which, like that of all tissues, contains much potash and phosphate of lime, while the fluids of the animal body are poor in these substances and rich in chloride of sodium; the ash of milk contains three to five times as much potash as soda, while the ash of blood, on the other hand, contains three to five times as much soda as potash. Were the milk simply a transudate from the blood, it would have a similar composition, and could not serve as the exclusive food of the young animal, since it would not contain all the elements necessary for growth; but since it is a liquefied organ, it is exactly adapted to build up other organs.

Structure of the Milk-Glands.—The milk-gland is composed of numberless small vesicles, like those represented in Fig. 8. They consist of a thin, structureless membrane, *a*, lined with epithelial cells, *b*. From three to eight of these vesicles are grouped together and surrounded by connective tissue, *d*, forming a lobule which has a common outlet, *c*, for all the vesicles. Several of these lobules, again, are united into a lobe, also surrounded by connective tissue, and having a common outlet, which empties into the milk-cistern.

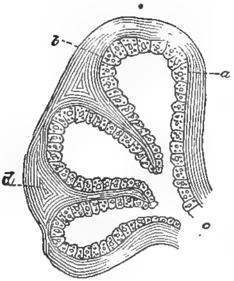

FIG. 8.—Lobule of Milk-gland.

The udder of the cow consists of a right and left half, each composed of numerous lobes surrounded by connective tissue. The two halves are separated from each other by a partition of connective tissue, and the whole is covered with more or less abundant fat-tissue, upon which follows the skin. Considerable fat is also found in the interior of the organ, and its amount may sometimes be so great that, in spite of an enormously large udder, there is only a small quantity of real glandular tissue, and the yield of milk is correspondingly scanty. In Fig. 9, *a* represents the mass of lobes; *b* shows several of the outlets

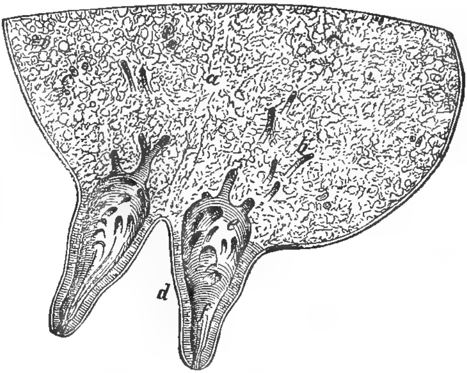

FIG. 9.—(Wilckens.) Section of a Cow's Udder.

of the lobes cut obliquely; *d* is the teat; *c* the milk-cistern, into which all the lobes empty; and *f* the outlet of the teat.

The vesicles above described are covered with a net-work of fine blood and lymph vessels, both of which are very fully developed in the udder. Each half of the udder has usually two, more seldom three, teats.

Formation of the Milk.—The space in the vesicles of the milk-gland contains originally only a small quantity of a yellowish mucus, but when conception takes place the cells begin to enlarge and to fill with fat-globules. At the same time new cells are formed, and the old ones are pushed forward and fill the vesicle, and, toward the end of pregnancy, even reach the large milk-ducts and the milk-cistern, partly separating from each other in the process. When birth takes place the cell-building in the vesicles becomes more rapid, and is somewhat altered in character. The previous secretions are the first to appear, forming the colostrum, which is followed in three or four days by the true milk.

The colostrum is a thick, yellowish fluid, rich in albumin and salts, but containing little casein, and characterized by the presence of round bodies, which are simply whole cells from the interior of the vesicles. The colostrum contains also a large number of the milk-globules shortly to be described.

In the production of the true milk, which soon follows the colostrum, a rapid formation of new cells takes place in the vesicles, these cells become completely filled with fat-globules, and then break up entirely, setting free these globules, which float in the fluid which is secreted at the same time, and form milk-globules. This process takes place much more rapidly than in the case of the colostrum, being wholly completed in the glands, so that the resulting milk shows no trace of the process, but appears like a homogeneous fluid.

Composition of Milk.—Under the microscope, milk is seen to consist of a fluid, in which are suspended the above mentioned milk-globules, which render the fluid opaque. On standing, these milk-globules rise to the surface and form the cream, while the liquid portion, more or less free from the fat-globules, forms skimmed milk.

It is in the composition of the fluid portion that milk shows most plainly that it is not simply a filtrate from the blood. It contains—in the case of the cow, *e. g.*—from two to five per cent. of protein; but while the protein of the blood exists as albumin or fibrin, only a very small part of the protein of milk consists of albumin, most of it existing as *casein* (see p. 17), a substance not found elsewhere in the body. A small amount of peptones is also found in milk.

Moreover, milk contains, in addition to the casein, from three to five per cent. of a peculiar sugar—milk-sugar, or *lactose*—which also has never yet been met with elsewhere in the organism. These two substances, together with the composition of its ash, stamp milk with a peculiar character, and are sufficient of themselves to show that it is not a secretion in the common sense of the word.

The milk-globules have given rise to much discussion. They consist essentially of a mixture of several fats, which, when separated from the milk or cream by churning, constitute butter.

The milk-globules are generally described as surrounded by a membrane consisting of some variety of protein. This membrane is not visible under the microscope, but several facts have been brought forward as proofs of its existence. Many eminent authorities, however, dissent from this view, and interpret the facts differently. The point is still an undecided one, and it will therefore suffice for our present purpose to have indicated the divergence of views upon it.

Sources of the Ingredients of Milk.—The *albuminoids* of milk are obviously derived from the albuminoids of the food or of the body. The albumin of milk seems to be identical with that of the serum of the blood, but the casein, as already noted, is not found in the body, but is a product of the action of the cells of the milk-gland.

The *fat* of the milk appears to be also formed from albuminoids. This is shown both by microscopic examination and by other facts. By means of the microscope, the formation of fat-globules in the epithelial cells of the gland may be seen. Moreover, experiments have shown that carnivorous animals, on a purely meat diet, produce normal milk, thus proving that milk-fat *may* be formed from albuminoids, and have also shown that the greatest quantity of fat is generally produced on a ration rich in protein. Experiments on herbivorous animals, to which reference has already been made (pp. 174–176), have shown no necessity for the assumption of a formation of milk-fat from carbhydrates.

The *milk-sugar* may also be formed from protein or fat, as the above-mentioned experiments on carnivorous animals show. In the case of herbivorous animals, however, it is probable that a part of it at least is derived from the carbhydrates of the food.

§ 2. The Quantity of Milk.

Fodder of Secondary Importance.—It is apparent at once, from the preceding section, that the quantity and quality of milk must be determined in the first place by the development of the milk-glands, and it is, indeed, perfectly well known that, with exactly the same fodder, one cow will give little and another much milk.

A poorly developed milk-gland cannot be stimulated to great production even by the richest food, and hence, in milk production, much depends on the choice of suitable animals. It is not, however, the size of the gland alone which is to be taken into consideration, but also its quality—its capability for rapid cell-building in the vesicles, which, as we have seen, is the essential part of the production of milk —and its ability to yield the desired quality of milk.

Such being the case, the food supply can have but a secondary importance; at the same time, the production of milk, like every other function of the body, demands a certain supply of food for its normal performance, and it is easy to see that the latter must exert a very considerable influence, at least on the quantity of the milk.

Period of Lactation.—Another factor having an important influence on the quantity of milk produced is the period of lactation. In the same animal, and with uniform feeding, the greatest yield of milk is generally obtained shortly after calving. At that time the milk-gland reaches its greatest development, and consequently produces the most milk, while subsequently it retrogrades, and the flow of milk decreases correspondingly.

This gradual diminution in the daily yield of milk is to a degree independent of the fodder, although its rapidity can be influenced by the latter. Consequently, it is desirable, in investigations on milk production, to introduce at the end of each series of experiments a period in which the fodder is the same as in the first period, in order to be able to take account of the extent of this diminution.

The Supply of Protein.—The formation of milk consists essentially in a rapid growth of new cells in the milk-glands. These cells consist largely of protein, and we should therefore expect their formation to be more or less dependent on the supply of protein in the food. Moreover, not only the protein of the milk, but also its fat, and perhaps part of its sugar, appear to be formed from albuminoids, and thus a further necessity for an abundant supply of these substances arises.

In fact, all experiments agree in showing that the greatest yield of milk is obtained with a fodder rich in protein. The size and quality of the milk-gland, it is true, determine the maximum amount of milk that can be formed, but this maximum can be reached only by means of a liberal supply of protein.

Another effect of protein, which shows itself in all experiments, is to augment the percentage of solid matter in the milk—*i. e.*, to make it less watery. Since, now, the amount of real production which takes place, as well as the true value of the milk, is measured by the amount of solid matter in the latter, it is evident that we must reduce the quantities of milk produced in any experiment to a uniform water-content before we can properly compare them. The basis usually adopted is 88 per cent. water and 12 per cent. solid matter, and from the actual quantity of milk produced is calculated the quantity which would have been produced had the amount of solid matter present been contained in milk having 88 per cent. of water.

Experiments by Wolff.—Some experiments by Wolff,* in 1868, though imperfect in some particulars, illustrate the influence of the protein of the fodder on the quantity of the milk.

In the first and last periods the fodder was the same, and from the difference in the yield of milk it was calculated that the average decrease per day due to the progress of lactation was 0.0234 lb. The amount of non-nitrogenous matter in the fodder was practically the same in all the periods, only that of the protein being varied. The following table shows the amount of crude protein fed per day, the yield of milk per day, its percentage of dry matter, the yield of milk reduced to a uniform water-content of 88 per cent., and the amount which would have been yielded had the fodder remained the same as in the first and last periods:

Period.	Crude protein fed. Lbs.	Yield of milk. Lbs.	Dry matter of milk. Per cent.	MILK WITH 88 PER CENT. WATER.	
				Found. Lbs.	Calculated. Lbs.
1.	2.52	19.8	11.38	18.8	18.8
2.	3.18	19.9	11.43	18.9	18.5
3.	3.86	20.0	11.46	19.1	18.3
4.	4.17	19.7	11.61	18.9	18.0
5.	3.34	18.5	11.71	18.0	17.8
6.	3.73	18.3	....	....	....
7.	4.15	18.3	11.50	17.5	17.4
8.	4.50	18.2	11.88	17.9	17.1
9.	2.95	17.1	11.84	16.8	16.8

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* "Ernährung Landw. Nutzthiere," p. 503.

In general, the percentage of dry matter in the milk was increased by the large proportion of protein, while the quantity of milk (reduced to a uniform water-content) is in every case greater than the calculated amount.

Experiments by G. Kühn.—Very extensive experiments upon the influence of the food on the production of milk have been made by Gustav Kühn, at the Möckern Experiment Station.* The following selection from his results will serve to illustrate the influence of a ration rich in albuminoids upon the quantity of milk.

The experiment was made on two cows, and was divided into four periods. In the first period each cow received a so-called normal fodder, which was poor in protein and consisted, per day, of

16.5	lbs. of	hay.
3.3	"	barley straw.
38.5	"	mangolds.

In the second period this ration was improved by the addition of 6.6 lbs. of palm-nut meal, which was replaced in the third period by an equal amount of beans. In the fourth period each cow received 27.5 lbs. of hay, and in the case of cow No. I. a fifth period was added, in which the fodder consisted of 27.5 lbs. of hay and 6.6 lbs. of palm-nut meal. The digestibility of the fodder was not determined in these experiments, but it is evident that the highly nitrogenous bye-fodders used must have largely increased the proportion of protein in the ration.

The several periods extended over from three to nearly seven weeks, during which time the fodder was accurately weighed out, the yield of milk weighed, and almost daily analyses of it made.

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* Jour. f. Landw., 1874 to 1877.

The results were in nearly all respects the same with each animal, and hence only those obtained with cow No. I. are given here. The following table * shows the average amount of milk given per day in the several periods (including the preliminary feeding) under the influence of the varying fodder:

Period.	Length of period.† Days.	Fodder.	Milk per day. Lbs.	Dry matter of milk. Per cent.	Milk with 88 per cent. water. Lbs.
1.....	35	"Normal fodder."	26.36	10.93	24.02
2.....	47	Same + 6.6 lbs. palm-nut meal	28.25	11.72	27.59
3.....	26	" +6.6 " beans.	29.39	11.33	27.76
4.....	21	27.5 lbs. hay.	22.86	10.88	20.72
5.....	21	Same +6.6 lbs. palm-nut meal	23.54	11.17	21.91

In these experiments the natural decrease in the flow of milk with advancing lactation is not taken into account, it having been found, in previous experiments on the same animal, to be very small.

The increased yield of milk, under the influence of the more nitrogenous fodder of periods 2, 3, and 5, is very marked, whether we consider the actual yield of milk or reduce it to a uniform water-content. The increase in the percentage of dry matter in the milk is equally evident.

These results show plainly that a liberal supply of protein in the food favors an abundant production of milk;

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* Jour. f. Landw., 1876, p. 190, and 1877, p 334.

† Including the preliminary feeding.

and this conclusion is confirmed by a large number of other investigations.

Effect of Fodder in Maintaining the Flow of Milk.—In the second and third periods of the above series, extending together over nearly two and one-half months, it was observed that the larger yield of milk caused by the richer food showed itself at once, and continued without very much alteration till the beginning of the fourth period. Indeed, the yield was somewhat greater during the last part of the third period than during the first part of the second period.

This illustrates a fact which has been frequently observed, viz.: that a rich fodder can render the natural depression due to the progress of lactation very small, and ensure a nearly constant flow of milk for a considerable time. Evidently this is no small gain, and one which becomes more manifest from day to day.

In the fourth period, in which the animal was fed on hay exclusively, a rapid diminution in the flow of milk was observed, evidently due to the poorer fodder. In the fifth period the fodder was improved, and rendered about equal in quality to that fed in the second and third periods. As a result, we have an increased secretion of milk, but neither on the average nor on any single day was the quantity nearly as great as before on a similar fodder.

We thus see that, while a good flow of milk may be maintained for a long time by means of a suitable fodder, it falls rapidly when the fodder is made poorer, and that when it has thus fallen it does not increase again to the former amount on a return to the old fodder. In this case three weeks of hay feeding sufficed to diminish the average daily yield of milk by about five pounds.

Milk Production with Insufficient Protein.—A fodder somewhat less rich in protein than that usually considered necessary will, it is true, if agreeable to the animals, often produce a large flow of milk. The energy of production is so great in good milk cows that it continues for a time unaltered, even when the fodder does not supply sufficient materials. The deficiency is then supplied from the body of the animal, and the latter loses flesh and fat.

This may be admissible to a certain extent in the early part of lactation, since, as the amount of milk gradually decreases, the drafts on the materials of the body cease, and the latter, if the fodder be tolerably rich, may regain what it previously lost. At the same time the deficiency must not be too great, since then, as we have just seen, a rapid decrease in the flow of milk takes place, and the cows are liable to come into a condition in which even rich feeding will not produce much milk.

Effect of Fat.—An increase of the fat of a ration seems to produce but little effect upon the milk production. The only conclusion that can be drawn from the experiments as yet made is that it does not increase at all the percentage of fat in the milk, but may slightly increase the quantity of the milk, probably because the fat protects some of the protein of the food from oxidation, and thus, by putting more material at the disposal of the milk-glands, causes an increased production of *all* the ingredients of the milk, and not simply of fat.

For example, in experiments by Wolff,* the addition of a pound of fat (at first rape-seed oil, afterward linseed oil) per head to a very scanty fodder which had caused a rapid decrease in the flow of milk increased the flow only for the first few days. On the average of the whole period of feeding almost no gain was obtained, and the percentage of fat in the milk actually *decreased* a little, as did also that of the total solid matter.

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* Loc. cit., p. 506.

In a similar experiment by G. Kühn, with a comparatively rich fodder, it was found that the addition of a pound of rape-seed oil per day and head caused a small increase (about one pound per day) in the daily milk production, while the percentage of fat remained unaltered.

§ 3. The Quality of the Milk.

By the quality of milk and its products is frequently meant those properties, like taste, color, etc., which render them more or less agreeable as food. These properties we shall not consider here to any extent, because, although of importance, and though they are affected by the feeding, the chemical changes which produce them are so slight as largely to escape observation, and because their causes are not yet well ascertained.

On the other hand, the changes in the proportions of water, casein, albumin, etc., which may take place in the milk, are also changes in the quality of the latter, and to the quality of the milk in this sense we shall here devote most of our attention.

Individual Peculiarities of Animals.—The quality of milk is stilll less dependent on the fodder than the quantity.

By far the most important factors determining the quality are the breed and individual peculiarities of the animal, especially as regards the properties of the milk-glands. The best and most abundant feeding is incapable of altering a "cheese breed" into a "butter breed," or *vice versa*. This can be accomplished, if at all, only by continued and intelligent breeding with this end in view, and not by a simple alteration of fodder. At the same time the fodder can affect the quality of the milk to some extent.

Influence of Fodder on Percentage of Dry Matter.—As already noted, the percentage of total dry matter in milk may be considerably increased by rich feeding. This is shown both in Wolff's and Kühn's experiments (pp. 421 and 423), and has been fully confirmed in many other investigations. In Wolff's experiments the addition to the fodder was solely protein. In Kühn's experiments both protein and non-nitrogenous nutrients were added, but since other experiments have shown that the addition of non-nitrogenous nutrients to a ration does not affect essentially either the quantity or quality of the milk, we must conclude that in this case also it was the additional *protein* which caused the gain.

The increase in the proportion of dry matter in the milk probably explains the common observation that it is possible to increase the yield of butter, *e. g.*, from a given amount of milk by means of proper feeding, although, as we shall see, the fodder does not usually alter the proportion of fat in the dry matter of the milk.

Influence of Fodder on Composition of Dry Matter.—In considering the influence of the fodder on the composition of the dry matter of milk there are certain facts that must be taken account of.

It is a well-ascertained fact that the quality of milk, particularly its proportion of fat, varies considerably from day to day, and even from one milking to another. Moreover, such variations are particularly liable to take place after a change of fodder. As a consequence, any conclusions based on a single or on a few analyses of milk, especially if executed shortly after a change of fodder, have absolutely no value.

These changes in the composition of the dry matter of the milk, however, mutually compensate each other, and the average composition for a long period is found in almost all cases to be unaffected by the fodder.

For example, in Kuhn's experiments, already cited, the quality of the milk was determined by means of a large number of analyses. In the following table* is given the average composition of the milk obtained in the several periods of the experiments described on page 422, both from cow No. I. and also from No. II. The milk, in every case, has been reduced to a uniform water-content of 88 per cent., thus eliminating the influence of the varying percentage of water in the natural milk.

Cow I.

Period.	Length of period. Days.	Dry Matter of fresh milk. Per cent.	MILK WITH 88 PER CENT. WATER.			
			Fat. Per cent.	Casein. Per cent.	Albumin. Per cent.	Sugar. Per cent.
1.......	35	10.93	3.33	2.25	0.25	5.08
2.......	47	11.72	3.81	2.26	0.24	4.76
3.......	26	11.33	3.51	2.38	0.26	5.03
4.......	21	10.88	3.46	2.36	0.23	5.27
5.......	21	11.17	3.76	2.38	0.24	5.08

Cow II.

1.......	31	10.37	3.44	2.24	0.30	4.98
2.......	41	10.80	3.44	2.40	0.31	4.69
3.......	27	10.55	3.15	2.47	0.35	5.10
4.......	21	10.50	3.30	2.48	0.31	5.16

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* *Loc. cit.*, 1877, pp. 334 and 352.

When calculated to a uniform water-content, the proportions of the several ingredients of the milk are practically the same, whatever the fodder. The same result has been obtained in many other experiments, in which the variations of the fodder were very great. The quantity of the milk and the percentage of dry matter varied, but the *relative* quantities of the several solid ingredients remained very constant.

One exception to this, however, appears in the above experiments. In periods 2 and 5, in which palm-nut meal was fed, the milk of Cow I. showed a noticeably increased percentage of fat, while that of Cow II. was not affected in this way. That this effect was not caused by the greater supply of protein is shown by the facts that it was produced in only one animal, and that it did not show itself in period 3, in which the fodder was even richer in protein than in period 2. That it was not due to the fat of the palm-nut meal follows from the fact that, in other experiments, the addition of fat to the fodder has had no such effect.

It would thus appear that the palm-nut meal exerted a specific effect on the milk production of this cow. In later experiments, the effect on the same animal was confirmed, and another cow, of a different breed, was found in which the same result was produced.

These two results are the only ones of the kind yet reached, all other experiments having failed to show any permanent change in the composition of the dry matter of the milk as a result of change of feeding. They are too few to justify any general conclusion, but it would be highly interesting to follow up the hint thus given, and to test various fodders and different animals in this respect.

Influence of Fodder on Quality of Butter.—Besides the well-known effect of certain fodders in imparting an undesirable flavor to butter, it is a fact of common experience that winter butter is inferior to that made on good pasturage. These differences in quality, however, seem to be due rather to the presence or absence of minute quantities of coloring and flavoring matters than to any recognizable change in the chemical composition of the fat.

Butter-fat consists essentially of a mixture of stearin, palmitin, and olein, and it is sometimes stated that when an animal is kept on poor fodder, particularly coarse fodder, the proportion of the solid stearin increases, and that of the softer palmitin and olein decreases.

Some recent experiments by Weiske* seem to indicate that this is not the case. They, at least, failed to show any alteration in the composition or melting-point of the fat of goat's milk as a consequence of poor or good feeding.

Other Conditions Influencing Quality of Milk.—Various circumstances, largely independent of the individuality or the feeding of the animal, affect the quality of the milk, especially its percentage of total dry matter. The milk of a large milker is generally more watery than that from a cow which produces a less quantity. With the same animal the percentage of total dry matter increases with the time that has elapsed since calving; that is, as the quantity gradually decreases, the milk grows more concentrated, the relative quantity of casein generally increasing somewhat at the same time, and that of fat decreasing. Similarly, as the yield of milk increases from one year to another up to a certain age of the animal, the percentage of dry matter decreases.

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* Jour. f. Landw., 1878, p. 447.

Even the milk drawn at different hours of the day from the same cow is by no means always of the same quality. The longer the time from one milking to another, the more watery is the milk; so that if the cows are milked three times daily, the morning milk is more watery than the noon or evening milk.

Still more striking are the differences observed in different portions of milk from the same milking. The milk which is first drawn from the udder is always far more watery and poorer in fat than the last portions drawn.

These circumstances, of course, must all be taken into account, and the possible errors arising from them avoided in any experiments upon the effect of feeding on the quality of the milk. This can only be done by extending the observations over a considerable time, and making a large number of milk analyses. Results based on but a small number of analyses, or covering but a short period, are to be accepted with great caution.

§ 4. The Feeding Standard.

The Nutritive Ratio.—All experiments on milk cows agree in showing that an abundance of protein in the fodder is an essential condition of the maximum production of milk. This implies a rather narrow nutritive ratio, since otherwise the quantity of protein in the amount of fodder which could be eaten would be too small.

It is true that a large supply of protein and a narrow nutritive ratio tend to increase the protein consumption in the body, and for that reason the nutritive ratio must not be made too narrow. At the same time, there is less fear of this effect with milking animals than with others, because much of the protein goes to sustain the activity of the milk-glands, and is not added to the stock of circulatory protein.

Organic Nutrients.—The following feeding standard, based on the numerous feeding experiments on milk cows already made, is the one recommended by Wolff:

FEEDING STANDARD FOR MILK COWS.—PER DAY AND 1,000 POUNDS LIVE-WEIGHT.

Digestible protein	2.5 pounds.
" fat	0.4 "
" carbhydrates	12.5 "
Nutritive ratio	1 : 5.4
Total dry matter	24 pounds.

These quantities correspond to the feed which the animals would obtain on good pasturage. If they are fed with average hay, it is necessary to add to it some rather nitrogenous and easily digestible feeding-stuff, in order to bring the ration up to the standard and ensure an abundant flow of milk.

The quantity of the non-nitrogenous nutrients may be increased beyond the amount given above, if the fodder at disposal permit; but such an increase will hardly be of any special advantage in the production of milk, as has been shown in experiments by Kühn and Stohmann.

Variations from Feeding Standard.—It is sufficiently evident, from the facts concerning milk production already presented, and from the considerations advanced in the chapter on Feeding Standards, that a feeding standard like that just given can have only a general value, and that the feeding must be largely influenced by the individuality of the animal and by the amount of milk which it is desired to produce.

The maximum amount of milk which a cow can produce is determined by the size and quality of her milk-glands, and the richest fodder which can profitably be given is that which just suffices to ensure that maximum yield.

On the other hand, the least amount of fodder which can safely be given is that which maintains a moderate flow of milk without drawing on the materials of the body.

Between these two limits the choice of fodder will be determined largely by financial considerations. When fodder is expensive and the price of milk is low, a poorer fodder than that called for by Wolff's standard might be in place, such as would result from decreasing the digestible protein of the ration while leaving the amount of digestible carbhydrates about the same. If oil cake were used, the change might be effected very simply by decreasing the quantity of this feeding-stuff. On the other hand, when fodder is cheap and the price of milk is high, it might be desirable to feed more richly than is indicated by the standard. This might be done by increasing the amount of digestible protein by the addition of some highly nitrogenous bye-fodder; but the amount of non-nitrogenous nutrients should be somewhat increased at the same time, in order that the nutritive ratio may not be too narrow.

In general, a given increase in the protein of the fodder produces a less effect on the amount of milk the nearer we approach to the maximum yield possible. Thus, if the addition of a pound of oil cake to a ration causes an increase of a quart per day in the amount of milk obtained, the addition of a second pound will cause a less gain, perhaps not more than a pint, while a third pound might cause hardly any gain. Moreover, the individuality of the animal will have a considerable influence on the return obtained from an increase of the fodder, and consequently on the determination of the most profitable ration.

Inorganic Nutrients.—A few words may, perhaps, be added in regard to the supply of inorganic nutrients, the importance of which has more than once been alluded to. In some experiments on goats, made at Proskau, in which the fodder contained no lime or phosphoric acid, the quantity of milk decreased rapidly, and the animals sickened, and died on the fifteenth day. It has also been observed that animals which receive no inorganic food, but an abundance of organic nutrients, die more quickly than those which receive no food at all.

As regards the feeding of milk cows, however, the matter is of little practical importance, since the ordinary fodders contain an abundance of all the necessary ingredients.

According to the Weende experiments (p. 376) the daily maintenance fodder of full-grown oxen contains approximately the following amounts of the more important inorganic nutrients:

Phosphoric acid	0.05 lb.
Lime	0.10 "
Potash	0.20 "

Adding to these the amounts contained in an average daily yield (say 20 lbs.) of milk, viz.:

Phosphoric acid	0.04 lb.
Lime	0.03 "
Potash	0.04 "

we get approximately the amount required by milk cows, viz.:

Phosphoric acid	0.09 lb.
Lime	0.13 "
Potash	0.24 "

These quantities are more than supplied by any ordinary ration, and only in case of almost exclusive feeding with straw, chaff, and roots is it, perhaps, advisable to add a little lime to the fodder, in the form of lixiviated chalk or *fine* leached ashes. The latter should be sifted before using. Potash is always present in more than sufficient quantity in all vegetable products.

Common salt constitutes, of course, an exception to the above remarks. The large amount of potash salts in the ordinary fodder of milk cows causes an increased excretion of soda salts from the body (see p. 24), and calls for a supply in the food. Salt also increases the palatability of the fodder and stimulates the appetite, a point the importance of which has already been alluded to.

CHAPTER VI.

FEEDING GROWING ANIMALS.

§ 1. GENERAL LAWS OF THE NUTRITION OF YOUNG ANIMALS.

THAT there are great differences between the nutritive processes in mature animals and those taking place in young individuals is evident to the most casual observation. While in the former case the food consumed is nearly all used to keep up the vital processes, and, under the most favorable circumstances, only a comparatively small fraction of it can be diverted to purposes of production, in the young animal a large portion of the food eaten is directed to productive purposes, viz., the growth of the muscles, bones, and other tissues.

But while these differences have been recognized, they have not yet been made the subject of much scientific study, and hence much of the necessary groundwork of a rational feeding of young animals is still lacking, and we are obliged to proceed on uncertain deductions from our knowledge of the nutritive processes in mature animals, combined with the results of practical experience.

Among the few accurate experiments on this subject are those of Soxhlet, in Vienna, upon the nutrition of young calves,* and this section is based essentially on his results.

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* Biedermann's Central-Blatt für Agr. Chem. Jahrg. VII., 748 and 887.

Amount of Food consumed.—Soxhlet's experiments were made with three young calves from eight to thirty days old, fed with milk, of which they were given approximately the amounts which they had been found to consume in preliminary trials. The following table exhibits the amount of the several nutrients consumed by an average animal two to three weeks old and weighing 100 pounds, and may be called the feeding-standard, so far as such a standard can be deduced from so few experiments. The quantities here given are, without doubt, abundant.

Consumption per Day and 100 lbs. Live-weight.

	Lbs.
Fresh milk	16.20
Total dry matter	1.93
Protein	0.49
Fat	0.47
Carbhydrates (milk-sugar)	0.84
Ash	0.13
Nutritive ratio	1 : 4.0

The average gain of weight per day was 1.85 pound.

In regard to the digestibility, it may be said that the milk was almost completely digested; only about 2.3 per cent. of the dry matter appeared in the excrements, so that for our present purposes no deduction need be made on this account from the above figures.

It will be observed, in the first place, that the food produced a much greater increase of weight than is the case with mature animals, one pound of dry matter of the food producing a gain of almost a pound in weight. The cause of this we shall consider later.

The following table gives a comparison of the *total nutritive matters*, *protein*, and *nutritive ratio* of the above ration (calculated on 1,000 pounds live-weight) with the corresponding quantities in the food of various other animals:*

	Total nutritive matter. Lbs.	Digestible protein. Lbs.	Nutritive ratio.
Oxen at rest....................	8.85	0.7	1 : 12
Sheep "	13.15	1.5	1 : 8.0
Fattening oxen	18.50	3.0	1 : 5.5
" sheep	18.50	3.5	1 : 4.5
Dog .... *a*	8.73	3.0	1 : 4.5
Dog .... *b*	15.70	5.1	1 : 5.0
Calf	19.30	4.9	1 : 4.0

Both the total quantity of nutritive matter consumed by the calf and the amount of protein will be seen to be relatively greater than in the case of any of the other herbivorous animals, while the nutritive ratio is narrower.

The food of the young calf approaches more nearly in its composition that of well-fed carnivorous animals, as represented by ration *b* for the dog; and the resemblance becomes still more close when we consider the comparatively large amount of fat in the food of the calf.

The greater *relative* consumption of food by young animals, as compared with mature ones, is also strikingly shown in the experiments on lambs described in § 3 of this chapter.

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* The rations for oxen and sheep are Wolff's feeding-standards. Of the two rations for the dog, *a* consists of 500 grms. fresh meat and 200 grms. fat—quantities which Voit found sufficient to keep an animal weighing about 70 lbs. in fair condition—and *b* is a richer ration, consisting of 800 grms. fresh meat and 350 grms. fat.

Production of Flesh.—We have already learned that the proportion of the albuminoids of the food which is converted into flesh is quite small in full-grown animals, while by far the larger proportion of the protein is decomposed in the body and excreted in the urine. In the young calf, on the contrary, more protein is retained in the body than is oxidized and excreted, the result being a rapid gain of flesh. The following table shows the relation between consumption and gain of protein per day for an average animal weighing 100 lbs.:

		Nitrogen.	Equivalent to protein.
Eaten	Pounds..	.078	.488
Excreted in dung	"	.004	.025
Digested	"	.074	.463
Excreted in urine	"	.020	.125
	%	27	27
Retained in body	Pounds..	.054	.338
	%	73	73

Notwithstanding the large amount of protein eaten and the narrow nutritive ratio, both of which circumstances tend to increase the protein consumption in the body, the young calf excretes a comparatively small quantity of nitrogen in the urine. While it eats nearly as much protein as a well-fed dog of equal weight, it excretes about as much as the latter animal does in hunger.

In other words, the sucking animal (in case of the calf at least) is able to apply a far larger proportion of the albuminoids which it receives in its food to the building up of its body than is the case with mature animals. Combining this with the relatively larger amount of food eaten, we can readily understand the rapid increase in weight of young animals.

Production of Fat.—By means of a respiration apparatus, the excretion of carbonic acid in these experiments was determined. The following table gives the result per day for the average animal of 100 lbs. weight, and also a comparison with the amount excreted per 100 lbs. body-weight by other animals:

Calf	1.95 lbs.
Man	1.3—1.4 "
Dog (in hunger)	1.1 "
" (well fed)	1.8 "
Ox (maintenance fodder)	1.0 "
Ox (fattening)	1.3 "
Sheep (maintenance fodder)	1.7 "

The excretion of carbonic acid is, in general, relatively greater in the calf than in mature herbivora, and approaches that of the well-fed carnivora.

The gain of carbon and consequently of fat per day was also considerable.

CARBON PER 100 LBS. LIVE-WEIGHT.

In food	0.98 lbs.
Excreted	0.53 "
Gain	0.45 "
Contained in the protein gained	0.18 "
Gained as fat	0.27 "
Corresponding to fat	0.35 "
Fat in the food	0.47 "

The amount of fat in the food was sufficient to supply all that was gained.

Inorganic Nutrients.—In one experiment the consumption and excretion of the mineral ingredients were determined. The results on an animal weighing 151.2 lbs. were the following:

	Consumed. Grms.	Excreted in urine and dung. Grms.	RETAINED.	
			Grms.	Per cent.
Total ash	81.34	37.20	44.14	54.30
Phosphoric acid	25.34	6.53	18.81	74.23
Chlorine	8.85	8.30	0.55	6.22
Lime	19.13	0.38	18.75	98.00
Magnesia	1.80	1.08	0.72	40.00
Potash	20.70	15.58	4.49	22.37
Soda	5.57	4.16	1.41	25.31
Iron	0.15	0.10	0.05	33.33

The large amounts of lime and phosphoric acid retained in the body are specially noteworthy. These substances are the chief inorganic ingredients of bone, and their almost entire retention, particularly that of the lime, in the above experiment, indicates the importance of an abundant supply of these ingredients in the food of growing animals.

Soxhlet remarks that it would seem that the milk of our cattle is so poor in lime that it contains barely enough to supply the wants of the young animal, and that it may be advisable to help out the supply by the addition of chalk (carbonate of lime). This would answer the purpose of supplying material for bone-building as well as the more costly phosphate of lime, since, according to the above results, a lack of phosphoric acid is not to be feared.

§2. CALVES.

In the foregoing pages we have endeavored to deduce, from experiments on calves, some principles which may serve as the groundwork for practical conclusions. The data for this are, indeed, scanty, and the whole subject of the feeding of young animals needs accurate scientific investigation. At the same time, we know enough to enable us to deduce some useful hints and indications.

Before weaning, milk usually forms the chief or only fodder. For the first few days after birth it is especially important that the calf have the milk of its own mother. The so-called colostrum (p. 416) has an essentially different composition from the milk produced later, containing far more dry matter and considerable albumin, while the amounts of fat and sugar are relatively less; the nutritive ratio is narrower, and the digestibility apparently greater.

These differences nearly disappear in the course of a week (sooner in cows yielding much milk than in those yielding little), and after this it is a matter of indifference, so far as the nutritive effect is concerned, whether the calf be fed from its own mother or not.

Nutritive Ratio.—That a milk diet is capable of supplying material for rapid growth is matter of common experience, and is illustrated by the experiments of the preceding section. The comparatively narrow nutritive ratio of good milk does not cause that waste of protein which it would in mature animals, and the calf is thus enabled to consume relatively large quantities of this most important of all nutrients in a small bulk, and thus to supply the body with abundance of material for growth.

It would seem from some experiments, however, that the nutritive ratio may in some cases be advantageously made wider, especially if the milk is very rich. In some experiments made long ago in Saxony,* three calves, fourteen days old, and weighing 117, 130, and 114 lbs., were fed daily as follows: No. 1 with 13.2 lbs. cow's milk and 13.2 lbs. whey; No. 2 with 22 lbs. of skimmed milk; and No. 3 with 17.6 lbs. milk and 3.9 lbs. cream.

The average consumption and the gain in weight per day were as follows:

	CONSUMED.				Nutritive Ratio.† 1 :	Gain per day. Lbs.	Pounds of organic matter to 1 lb. of growth.
	Organic Substance. Lbs.	Protein. Lbs.	Sugar. Lbs.	Fat. Lbs.			
No. 1...	2.3	0.54	1.29	0.51	4.8	1.88	1.35
No. 2...	2.0	0.70	1.02	0.22	2.2	1.14	1.88
No. 3...	3.0	0.73	1.02	1.22	5.6	3.38	0.97

It will be seen that the gain in weight was strikingly different, according to the food used.

The least gain was made in the second experiment, where the nutritive ratio was very narrow. In this case there is little doubt that, in spite of the comparatively small protein consumption of young animals, a considerable waste of protein must have taken place, resulting in a small gain.

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* Wolff: "Landwirthschaftliche Fütterungslehre," p. 152.

† In calculating the nutritive ratio, the fat has been converted into its "starch-equivalent" by multiplying it by 2.5. The milk used in these experiments was rather rich in nitrogen and poor in fat. With more average milk, the nutritive ratio in No. 1 and No. 3 would have been still wider.

In the third experiment the food was the same as in the second, with the addition of a pound of fat per day. This addition of fat evidently rendered the protein consumption less, while also supplying more material for fat formation, and, as a result, a very marked gain was produced. The amount of organic matter required to produce a gain of one pound was also less in this case than in either of the others, and somewhat less than in Soxhlet's experiments.

A comparison of the first and second experiments is especially instructive. The total amount of nutritive matters consumed in the two cases was about the same, but the wider nutritive ratio of the first experiment caused a greater and more economical gain.

Sugar in Place of Fat.—The first of the above experiments is particularly interesting as showing that a satisfactory gain may be brought about by a ration comparatively poor in protein, but having a rather wide nutritive ratio, and also that sugar may be advantageously used instead of the more costly fat to produce this wider nutritive ratio. This result is of practical value, because it seems to indicate quite clearly that even with pretty young calves a portion of the milk, perhaps half, may be replaced by whey,* or perhaps that skimmed milk,† with the addition of sugar or starch, may be used instead of whole milk.

It is questionable, however, whether the fat of the milk can be wholly replaced by carbhydrates with safety. Fat is the most concentrated of all the non-nitrogenous nutrients, and in the finely divided state in which it exists in milk is probably very easily digestible by the young animal. In addition to this, the greater palatability of normal milk is an important factor in determining the effect of feeding, as has already been explained in connection with other fodders. Whole milk is the natural fodder of young animals, and the one whose composition must be imitated as closely as possible in all attempts to substitute other materials for it, and which, for the first two weeks at least, should, if possible, form the only food.

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*In the manufacture of cheese, most of the casein and fat are removed from the milk in the curd, while the whey contains nearly all of the milk-sugar, together with a little fat and protein. (See Table of Composition of Feeding-stuffs in Appendix.)

† Skimmed milk has lost chiefly fat, which, on the above plan, would be replaced, at least to a certain extent, by starch or sugar.

During the first four to six weeks, an increase of 1 lb. live-weight is obtained, on the average, with about 10 lbs. of milk (1.25 lb. dry organic matter). At first the quantity of milk is a little less, and toward the close a little more. Since, however, the composition of milk is variable, the amount of fat, especially, varying from 2 to 5 per cent., and the nutritive ratio consequently from 1 : 3.3 to 1 : 5.5, it is easy to see why the effect produced by the same quantity of milk should vary considerably in different cases.

Substitutes for Milk.—It is sometimes desirable to replace the milk partly or wholly by other feeding-stuffs. In doing this, it should be the aim to compound a ration approaching milk as closely as possible, not only in composition, but also (and this is quite as important) in properties. It should be easily digestible, liquid if possible, and should be fed warm.

This is not the place to enter into a discussion of the various substitutes for milk which have been proposed. It is our office simply to point out the principle on which they should be based, viz., as close an imitation of the composition and properties of normal milk as possible.

The tables of the composition and digestibility of feeding-stuffs contained in the Appendix will aid in forming a judgment as to how far these conditions are fulfilled in any proposed substitute, while actual trial alone can fix its true practical value.

Weaning.—It is one of the feeder's chief problems to bring about the change from exclusive milk feeding to other fodder in such a manner as not only to cause no falling off in the condition of the animal, but so that a constant increase in the live-weight shall take place during, or at least immediately after weaning. This can only be accomplished by making the change as gradual as possible and replacing the milk by substitutes of suitable digestibility, palatability, and nutritive quality. Crushed and boiled flaxseed is at first very well suited to this purpose. Later, oil cake or palm-nut cake, and also oats, barley, malt sprouts, etc., can be profitably used, while by feeding the finest and tenderest hay the animals are gradually accustomed to coarse fodder.

When the calves can be early put upon good pasturage the weaning will accomplish itself; but where this is not the case and they must be stall-fed, more care is demanded. At first the same nutritive ratio should be maintained as in average milk, or, at most, it may be a little widened toward the end of the weaning. The fat of the milk, however, may be pretty rapidly replaced by a corresponding quantity of easily digestible carbhydrates, without, however, making the change too sudden. In this way the complete weaning of the calves may be accomplished by the end of the ninth or tenth week, or even earlier.

After Weaning.—After weaning it is advisable to continue for some time the use of quite concentrated food with a nutritive ratio of 1 : 5—6.

Soxhlet's experiments (p. 439) render it probable that all young and growing animals utilize a larger proportion of the protein of their food than mature animals, and only lose this power gradually as they approach maturity. A growing animal, then, may economically receive a relatively large proportion of protein, thus placing at its disposal an abundance of material for forming new tissue, while as it grows older either the amount must be decreased or more non-nitrogenous nutrients must be added to the ration in order to protect the protein from waste, *i. e.*, the nutritive ratio must be widened.

Moreover, the stomach of the young animal does not at once become capable of accommodating and digesting large masses of fodder, and hence its food must at first occupy a comparatively small bulk—must contain much nutriment in a small volume. It is desirable also that the fodder should not be too watery, for much the same reasons as those adduced under fattening.

When the animals have reached the age of six to nine months, however, the fodder may be gradually made more bulky and less rich in protein and nutritive matters in general, and roots may now be used more freely than before.

To obtain good milk cows, especially, the rich feeding must not be continued too long, as it tends to develop an inclination to fattening rather than to milk production. If, on the other hand, the animals are to be fattened, it might be an advantage to continue a pretty rich feeding.

In the feeding standards given in the Appendix these considerations have been taken into account. It is to be remarked, in regard to these standards, that they have their basis rather in practical experience than in exact scientific investigation, and, like all feeding standards, are subject to modification both by the experience of the user and the results of further investigation.

§ 3. LAMBS.

Quality of Fodder.—Young lambs increase in weight relatively more rapidly than calves, and easily suffer from insufficient food, and hence great care must be observed in feeding them. This is especially the case as regards the choice of the coarse fodder during and immediately after weaning.

Lambs do best upon good pasturage. If fed in the stall, they must receive only the best and tenderest hay. If the latter is even slightly too coarse or is unpalatable from any cause, such as unfavorable weather during its making, the animals will not eat a sufficient quantity, and will be strikingly retarded in their development. Even hay of average quality requires the addition of grain, best of oats, or of some other nitrogenous feeding-stuff.

FEEDING FOR MAINTENANCE.—**Wolff's Experiments.**—Some experiments made by Wolff,* at Hohenheim, on the digestibility of fodder by sheep of two different breeds, are also of value in fixing a feeding standard for lambs.

Four lambs of the so-called Württemberg bastard breed, about five months old and weighing about fifty pounds per head, were used. Similar experiments were attempted on Southdown lambs, but were interrupted by sickness of the animals. Two of the four lambs were fed with hay exclusively for nine months. The other two received, in addition, grain and oil cake, and fattened quite rapidly, while the first two received only maintenance fodder. We will take up first the results obtained on the hay-fed lambs, omitting, for the present, the question of fattening.

The experiment was divided into five periods, in each of which the composition and digestibility of the hay were carefully determined. In each period the animals received as much hay as they would eat, the amount consumed being, of course, carefully determined.

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* Landw. Jahrbücher, II., 221.

In the first and second periods the fodder was a very excellent quality of early-cut meadow hay, nearly 70 per cent. of the total organic matter of which was digested. In the third, fourth, and fifth periods it was rowen, which, indeed, was of good quality and was well digested, but which was unpalatable to the animals after the better fodder which they had received, the consequence being that they ate considerably less and gained little or nothing in weight.

The following table shows the average consumption of fodder per day and head, the amount of nutrients actually digested, and the gain in weight, for each of the five periods.

Period.	Age. Months.	Average weight. Lbs.	Hay eaten. Lbs.	DIGESTED PER DAY.			Gain per day. Lb.
				Protein. Lb.	Fat. Lb.	Carbhydrates. Lb.	
1	5–6	58.5	1.89	0.185	0.020	0.912	0.241
2	6–8	66.8	2.01	0.198	0.023	1.121	0.152
3	8–9	72.2	1.71	0.135	0.028	0.799	0.058
4	9–12	73.0	1.46	0.101	0 021	0.710	0.002
5	12–14	76.3	1.89	0.123	0.031	0.888	0.100

Effect of Change of Fodder.—In the first and second periods the gain was very satisfactory, but with the change of fodder at the beginning of the third period the amount eaten sank, and the gain per day dropped to nearly a third of the previous figure. In the fourth period this was still more marked, the fodder being barely sufficient to sustain the animals, and only in the fifth period, after four months, did the consumption of hay and the gain of weight rise again. A more striking example could hardly be given of the need of care in changing from a good to a poorer fodder in the case of young animals.

Feeding Standards.—It is probable that if the animals had been able to eat as much of the second fodder as of the first, or if some fodder which contained about the same amount of nutrients but was more palatable to the animals had been used, the gain of weight would have continued regularly, decreasing gradually with increasing age.

On the assumption that the results of the first, second, and fifth periods are normal, the feeding standards given in the Appendix have been calculated by Wolff. They are intended for animals of medium fineness of wool, and which, when full grown, weigh 90 to 100 lbs. Such animals, when fed in this way, will, on reaching the above weight, be in a well-fed condition and ready either for fattening or for wool production.

In the above experiments this result was obtained by the use of hay alone, but this course will only succeed when the hay is of very superior quality. When this is not the case, and a good pasture is not available, an addition of grain must be made to the hay ration, in order to bring the quantity of nutrients up to the standard.

It will be noticed that, according to the feeding standards deduced above, the quantity of protein required per day and head decreases as the age of the animals increases, and that the amount of the non-nitrogenous nutrients remains about the same, notwithstanding that the live-weight is continually increasing.

Young animals, as already stated (p. 438), need a relatively large amount of total dry matter and of digestible substance in their fodder, and gain weight with corresponding rapidity, while later, the necessary amount of food decreases quite rapidly, as does also the increase of weight. The more rapid gain in weight at first is doubtless caused, in part at least, by the power of the young animal to appropriate to the building up of its body a large proportion of the very considerable amount of protein contained in its fodder. Another circumstance, however, must be taken into account, viz., the fact that the flesh of young and rapidly growing animals contains a larger percentage of water than that of older animals. This fact should always be borne in mind in comparing the effects of a ration upon young and old animals simply by the gain of live-weight.

Weiske's Experiments.—Some recent experiments by Weiske* on the feeding of lambs are of interest in this connection. During nine consecutive periods of about one and one-quarter months each, covering the time from the fourth to the fifteenth month of the animals' age, the fodder of the animals was carefully weighed out each day, and any portions left uneaten were also weighed and deducted. At the close of the ninth period came a pause of about nine months, after which a tenth experiment was made, the animals being then full-grown.

The fodder consisted at first of hay and peas. As the experiments progressed the quantity of the former was gradually increased and that of the latter diminished, till in the eighth, ninth, and tenth periods the ration was composed exclusively of hay. In each period the live-weight, the digestibility of the fodder, and the excretion of nitrogen in the urine were determined, the investigation of the excrements and the weighing extending over eight days.

That the fodder was abundantly sufficient was shown by the regular increase in weight, and also by the fact that the animals gained weight faster than similar animals from the same herd on good pasturage.

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* Landw. Jahrbücher, IX., 205.

The experiments were begun with two animals, but, owing to various causes, accurate results could in several cases be obtained only on one. The numbers in the following table refer to lamb No. II., unless the contrary is stated. The ages given in the table are only approximate; the live-weight is in each case the average of eight weighings made toward the close of the period.

PER HEAD.

Period.	Age. Months.	Live-weight. Lbs.	Digested per Day.			Nutr. Ratio. 1 :	Gain per Day.	
			Protein. Lb.	Fat. Lb.	Carbhydrates. Lb.		Live-weight. Lb.	Flesh. Lb.
1.....	4–5¼	45.0	0.17	0.03	0.74	4.8	0.28	0.17
2.....	5¼–6½	56.2*	0.18	0.04	0.92	5.7	0.27	0.17
3.....	6½–7¾	63.5	0.18	0.04	0.90	5.6	0.23	0.15
4.....	7¾–9	71.7	0.20	0.04	0.98	5.4	0.20	0.18
5.....	9–10¼	77.0	0.18	0.04	0.95	5.8	0.13	0.15
6.....	10¼–11½	77.6	0.18	0.04	0.94	5.8	0.09	0.13
7.....	11½–12¾	83.6	0.18	0.05	0.96	6.0	0.13	0.19
8.....	12¾–14	89.1	0.17	0.05	0.99	6.6	0.16	0.16
9*....	14–15	85.8	0.16	0.04	0.98	6.8	....	....
10.....	24	126.5	0.15	0.06	1.18	8.9	....	0.14

These figures agree as closely as can be expected in experiments of this sort with the results obtained by Wolff, and show the correctness of the feeding standards recommended by him.

The amount of digestible protein required per day and head by lambs is shown by these figures to be essentially the same in all the periods, notwithstanding the increase in weight, while the quantity of non-nitrogenous nutrients increases slightly. In Wolff's experiments, both the protein and the non-nitrogenous nutrients decreased in quantity toward the end of the experiments. As already noted, Weiske's lambs grew faster than others of the same herd, and it is not unlikely that slightly less food would have given satisfactory results.

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* Lamb No. I.

The gain of live-weight diminished as the animals approached maturity, while the protein consumption, as well as the gain of flesh, per head, was found to be nearly constant throughout. If, however, the results are calculated per 100 pounds live-weight, as in Soxhlet's experiments on calves, we have a somewhat different showing. In the following table this has been done.

PER 100 POUNDS LIVE-WEIGHT.

Period.	DIGESTED PER DAY.			Gain of weight per day. Lbs.	Protein consumption per day. Lbs.	Gain of protein per day. Lbs.	Gain of protein in per ct. of amount digested.
	Protein. Lbs.	Fat. Lbs.	Carbhydrates. Lbs.				
1	0.38	0.07	1.67	0.73	0.29	0.09	23.7
2	0.33	0.07	1.66	0.54	0.26	0.07	21.2
3	0.28	0.06	1.41	0.41	0.23	0.05	17.9
4	0.28	0.06	1.36	0.31	0.22	0.06	21.4
5	0.24	0.05	1.23	0.17	0.20	0.04	16.7
6	0.23	0.06	1.22	0.13	0.19	0.04	17.4
7	0.22	0.05	1.15	0.17	0.17	0.05	22.7
8	0.20	0.05	1.11	0.19	0.16	0.04	20.0
9	0.19	0.06	1.09	....	....	....	....
10	0.12	0.05	0.93	....	0.10	0.02	16.7

We see that as the animals grew older the relative amount of food consumed decreased, and that the gain of weight likewise became less rapid. The protein consumption, too, decreased, in consequence of the diminished supply of this nutrient, and the gain of protein, though varying somewhat from period to period, also showed a decided decrease. The results regarding the percentage of the total digested protein which was retained in the body contrast strongly with those obtained by Soxhlet on sucking calves (p. 439), and show that the protein consumption increases quite rapidly in growing animals, and even at a comparatively early age becomes much greater than the gain of protein by the body.

The respiratory products were not determined in these experiments, but from the observed gain of nitrogen, sulphur, and mineral matters, it was calculated that the increase in weight in the first nine periods (53.9 lbs.*) had approximately the following composition:

	Lbs.	Lbs.
Dry protein (exclusive of wool)...............	8.29	....
Flesh " "	....	34.54
Pure wool (water-free)........................	2.43	....
Crude wool....................................	....	5.47
Fat and water.................................	37.03	....
Fat...	....	8.10
Mineral matters...............................	6.15	....
" " less those of crude wool.....	....	5.79
Total gain..........................	53.90	53.90

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* The gain in weight is the difference between the live-weight at the beginning of the first and the end of the ninth period, and hence is greater than would appear from the table on page 452, which gives only the *average* weight for each period.

These figures are interesting as showing the large gain of flesh made by the young animals, while, as we have seen, mature animals, even when highly fed, gain chiefly fat.

FATTENING. — **Wolff's Experiments.**—In the experiments by Wolff, partially described on page 448, two of the lambs received, in addition to the hay, oats, and oil cake, and at the close of the experiment were found to be well fattened. The following table shows the total amount of fodder (water-free) eaten, the amount of digestible nutrients, and the gain in weight, per day and head, for the several periods:

Period.	Age. Months.	Average live-weight. Lbs.	Total fodder. Lbs.	DIGESTED.			Nutr. Ratio. 1:	Gain per day. Lbs.
				Protein. Lb.	Fat. Lb.	Carbhydrates, Lb.		
1	5–6	59.7	1.99	0.21	0.08	0.97	5.6	0.26
2	6–8	70.7	2.02	0.24	0.08	1.02	5.1	0.24
3	8–9	78.9	1.91	0.21	0.10	0.92	5.6	0.07
4	9–12	84.8	1.82	0.19	0.06	0.91	5.6	0.12
5	12–14	95.8	1.76	0.19	0.08	0.89	5.7	0.19

In the last three periods the consumption of fodder fell off considerably, especially if we take into account the increased weight of the animals. The average consumption of digestible protein per day and head was 0.21 pound, and the nutritive ratio did not vary greatly from 1 : 5.6.

We shall not, therefore, err greatly if we say that a ration containing, per day and head, about 0.20 pound of digestible protein, and having a nutritive ratio of about 1 : 5.6, and fed constantly from the age of six months on, irrespective of the increase in weight, will, in eight to nine months, yield animals weighing in the neighborhood of 100 lbs., and well fattened.

Richer Feeding.—By richer feeding a still more rapid gain may be obtained.

In some experiments by Stohmann,* lambs seven to eight months old were fed for five months upon straw, potatoes, clover hay, and oil cake. These feeding-stuffs were combined into four different rations, two (Nos. 2 and 3) containing, per day and head, on the average, 0.28 lb. of digestible protein, and the other two (Nos. 1 and 4) about 0.38 lb. The quantity of non-nitrogenous nutrients was such that the nutritive ratio of one ration of each pair was wider than that of the other, as shown by the table on the opposite page.

All the animals gained weight rapidly, but it was observed that the rations containing the larger amount of protein, produced, as was to be expected, the greatest effect (compare p. 399 *et seq.*), and also that the wider nutritive ratios gave better results than the narrower, a thing which was also to be expected. The latter fact was especially noticeable after the animals were shorn at the end of the fourth month. After this, 0.46† lb. of protein per day, with a nutritive ratio of 1 : 3.9, not only gave a poorer result than about the same quantity with a ratio of 1 : 4.3, but hardly a better than 0.33† lb. of protein with a nutritive ratio of 1 : 5.3.

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* Jour. f. Landw., 1867, p. 133; "Ernährung der Landw. Nutzthiere," p. 439.

† The quantities of protein first given are the average amounts for the first four months. The actual quantity was gradually increased with the growth of the animals, and hence the average for the last month is higher.

The following table gives the average amount of digestible protein and non-nitrogenous nutrients, the nutritive ratio, and the gain in weight, per day and head, both before and after shearing. The experiments extended over four months before the shearing and one month after.

BEFORE SHEARING.

	Lot 1.	Lot 2.	Lot 3.	Lot 4.
Digestible protein. Lb.	0.38	0.28	0.28	0.38
Digestible non-nitrogenous nutrients. Lbs.	1.54	1.56	1.36	1.41
Nutritive ratio	1:4.1	1:5.6	1:4.9	1:3.7
Gain per day. Lb.	0.25	0.21	0.17	0.21

AFTER SHEARING.

Digestible protein. Lb.	0.48	0.35	0.33	0.46
Digestible non-nitrogenous nutrients. Lbs.	2.04	2.02	1.76	1.80
Nutritive ratio	1:4.3	1:5.8	1:5.3	1:3.9
Gain per day. Lb.	0.28	0.25	0.23	0.24
Average live-weight. Lbs.	95.00	92.00	86 00	92.00
Dressed weight in per cent. of live-weight	58.1	57.4	56.2	53.1

It was, of course, to be expected that, other things being equal, the ration furnishing the most protein would give the best results. A limit, however, exists in the fact that the animals can consume only a certain amount of food, and that consequently it is impossible to feed enough non-nitrogenous matters to prevent a waste of protein when a very large amount of the latter is given.

According to these results, a ration containing 0.28 to 0.38 lb. of digestible protein, per day and head, and having a nutritive ratio of about 1 : 5, will produce in about five months the same result as the poorer ration used in Wolff's experiments (p. 455) did in nine.

To attain such a result, however, care must be exercised in the choice of the feeding-stuffs, so as to ensure the complete consumption of the ration. Moreover, the cost of such feeding is an important consideration, and the farmer will do well to consider whether it would not be cheaper to use the poorer ration, or even to defer the real fattening until later. (See p. 402.)

It should be added that these feeding standards, like those for maintenance, apply to animals of medium fineness of wool, weighing, when full grown, 90–100 pounds. Fine-wooled animals generally require rather more food than coarse-wooled, and heavier animals need more than lighter.

§ 4. Pigs.

Variations in Fodder.—In regard to the feeding of pigs to be used for breeding, or which are to be fattened after reaching maturity, no exact experiments have been made.

More commonly, however, pigs receive a full fattening fodder from the time they are weaned, and the experiments on the fattening of pigs are quite numerous. These experiments have shown that the fodder of the pig may vary more in its composition than that of almost any other domestic animal, resembling in this respect that of carnivorous animals. It may be made very rich in protein, having a nutritive ratio of 1 : 2, or it may safely be made pretty rich in digestible carbhydrates. Adding to this the relatively large amount of fodder consumed by the pig, it becomes plain that both the nutritive effect and the cost of the feeding may vary greatly, and that consequently the feeding standards for pigs must be still more general in their nature than those for other animals.

Nutritive Ratio.—All experiments on pigs agree in showing that with young animals a *narrow nutritive ratio* produces the most rapid gain with the least expenditure of fodder, while as the animals grow older the best results, both as to rapidity of gain and quality of product, are generally obtained by using a somewhat wider ratio.

Of the numerous experiments illustrating this, the following by Lehmann* may serve as an example. The feeding-stuffs used were skimmed milk, peas, oats, barley, rye bran, and potatoes. Six animals were divided into three lots of two each: Lot I. received in each period a fodder having a nutritive ratio of about 1 : 4; Lot II. one having a nutritive ratio of about 1 : 6; and Lot III. one having a ratio of 1 : 8. The following table contains the principal results of the experiments:

PERIOD I.—13 Days (Age: 68–81 Days).

Lot.	PER DAY AND HEAD.				TO PRODUCE A GAIN OF 100 POUNDS.			
	Average live-weight. Lbs.	Gain. Lb.	Dry matter of fodder. Lbs.	Nutr. ratio. 1 :	Dry matter. Lbs.	Protein. Lbs.	Carbhydrates. Lbs.	Fat. Lbs.
I...	46.8	0.85	2.32	3.93	301.95	59.10	210.12	9.01
II..	44.6	0.76	2.31	6.13	333.85	44.95	258.72	6.81
III..	44.6	0.59	2.35	8.27	436.59	45.10	356.40	6.71

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* Wolff: "Ernährung der Landw. Nutzthiere," p. 466.

PERIOD III.*—29 Days (Age: 123–152 Days).

Lot.	Per Day and Head.			Nutr. ratio. 1 :	To Produce a Gain of 100 Pounds.			
	Average live-weight. Lbs.	Gain. Lb.	Dry matter of fodder. Lbs.		Dry matter. Lbs.	Protein. Lbs.	Carbhydrates. Lbs.	Fat. Lbs.
I ...	110.9	1.31	4.44	4.18	374.55	69.63	257.40	13.64
II ..	108.1	0.97	3.79	6.35	431.31	56.32	332.09	10.23
III..	90.0	0.85	3.41	7.80	439.01	44.55	357.17	7.48

PERIOD IV.—25 Days (Age: 152–177 Days).

I ...	143.6	1.12	4.65	3.94	465.19	90.97	323.29	14.08
II ..	136.7	1.10	4.36	6.12	435.71	58.74	337.59	8.91
III..	112.0	0.77	3.11	9.09	445.28	42.24	368.28	6.27

PERIOD V.—45 Days (Age: 177–222 Days).

I ...	190.6	1.41	5.32	3.64	416.24	85.91	282.26	12.87
II ..	189.2	1.71	5.40	5.78	347.27	49.28	264.66	8.36
III..	156.5	1.54	5.07	7.04	362.34	43.45	286.33	7.92

PERIOD VI.—66 Days (Age: 247–313 Days).

I ...	287.1	1.14	6.03	4.05	582.45	110.99	408.32	16.39
II ..	292.9	1.56	5.98	6.36	421.19	54.89	328.90	8.03
III..	241.2	1.07	4.85	8.76	498.52	49.17	409.97	8.14

An inspection of the table shows that up to Period IV. the fodder having the narrowest nutritive ratio produced the greatest gain and with the least expenditure of fodder. It is also noticeable that in nearly every case the animals ate more of the fodder in proportion as its nutritive ratio was narrower. In Period IV. the ration with a nutritive ratio of 1 : 6, produced a given gain with the least expenditure of fodder, although the gain per day was greatest in Lot I., owing to the greater amount of fodder eaten. In Periods V. and VI. the advantage is decidedly with the nutritive ratio 1 : 6, both as to the gain made and the expenditure of fodder.

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* The results of Period II., of 42 days, are omitted because sickness among the animals rendered them of doubtful value.

Very similar results have been obtained by numerous other observers. In all cases a narrow nutritive ratio during the first few months of feeding has given the best results, while widening the nutritive ratio as the animals grow older has almost always been found advantageous. Thus Heiden,* in his extensive feeding experiments on pigs, found that while peas and sour milk formed an excellent fattening fodder for pigs up to the age of about four months, much better results were reached after that time by the addition of potatoes to the ration.

Feeding Standards.—The feeding standards for pigs given in the Appendix are deduced by Wolff from the results of a large number of feeding trials. The narrow nutritive ratio there recommended for young pigs, and its gradual widening, are, as we have just seen, in accord with the results of experiment; the total quantity of fodder eaten is most naturally and simply determined by the appetite of the animal.

Although these highly nitrogenous rations cause the most rapid gain in weight, they appear of questionable advisability in so far as the animals are rendered more liable to over-feeding and to various diseases than when the fodder is poorer in protein. For the sake of greater security it may oftentimes be advisable to reduce the amount of albuminoids somewhat from that given in the standards, and to begin at once with a nutritive ratio of 1 : 4.5 or 1 : 5, widening it gradually after the fifth or sixth month till it reaches 1 : 6.5.

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* "Untersuchungen über die zweckmässigste Ernährung des Schweines," Hannover, 1879. Heft II., p. 92 et seq.

Another and very important point to be considered in the use of these narrow nutritive ratios is that of cost. The table on page 460 shows that although a given increase in weight was produced with the least fodder when that fodder had a narrow nutritive ratio, the quantity of *protein* required was in every case greater, while that of the carbhydrates was correspondingly less. As a general rule feeding-stuffs rich in protein, such as are necessary in compounding a ration having a narrow nutritive ratio, are rather costly, while the carbhydrates are comparatively cheap. The less cost of a ration having a wide nutritive ratio might, then, render its use more economical, in spite of the larger amount of it required to produce a given increase in weight. All these points, as well as practical considerations concerning the most suitable feeding-stuffs, must be taken account of in fixing on the most suitable ration for a particular case, and they obviously offer a wide field for the exercise of intelligence and good judgment.

§ 5. INORGANIC NUTRIENTS.

Importance.—Hitherto we have considered only the demands of various animals for the several organic nutrients. The greater quantity of these renders their importance more obvious, but at the same time the mineral ingredients of feeding-stuffs are no less essential, as has already been pointed out on pages 20 to 24. This is especially the case with growing animals, which have not only to replace the loss of these substances which is continually taking place, but also to provide material for new growth, both of bone and of the soft parts of the body.

Supply in the Food.—Although all the mineral ingredients of the body are *essential*, there are five substances which, on account of the large quantity of them which is required, may be said to be more important than the others; these are soda, potash, lime, phosphoric acid, and chlorine.

Of these, sodium (the basis of soda) and chlorine, combined to form common salt, occupy to a certain extent an exceptional position, as has already been explained, and the necessity for a sufficient supply of salt is generally understood and acted upon. Potash is contained in sufficient quantity, and generally in excess, in all ordinary feeding-stuffs. Lime and phosphoric acid, though they exist in large quantity in many feeding-stuffs, may sometimes be deficient, and these two substances are the principal ones which need be considered.

Of the common fodders, grass and hay, particularly clover, are quite rich in lime but comparatively poor in phosphoric acid. The same is the case with the straw of the legumes. The straw of the cereals contains rather more phosphoric acid than that of the legumes, but still has an excess of lime. Roots, being so watery, have relatively little ash, but contain more phosphoric acid than lime. The grains, and indeed all seeds, are rich in phosphoric acid and poor in lime.

Circumstances under which a Lack may occur.—These considerations make it evident that when an animal is fed largely or exclusively on coarse fodder, particularly on meadow or clover hay, a lack of phosphoric acid may occur, while lime would be plentifully supplied.

If, on the other hand, much grain, roots, and straw or chaff are fed, with little hay, a lack of lime might result. It seems not unlikely that this is sometimes the cause of the "bone hunger," which causes cattle to seek out and chew bones.

Calves and lambs are commonly fed on hay and grain, and under these circumstances experience has shown that a lack of lime or phosphoric acid is not to be feared, since these two classes of feeding-stuffs supply each other's deficiencies in this respect, grain containing much phosphoric acid and little lime, and hay much lime and little phosphoric acid.

Pigs, on the other hand, are frequently fed almost exclusively on grain and potatoes, with the addition of sour milk or skimmed milk. All these feeding-stuffs contain large quantities of phosphoric acid and but little lime (with the exception of milk), and experience has shown that the addition of a small amount of lime to the feed of pigs, either as chalk or carefully sifted leached wood ashes, is often of great value and is to be regarded almost as a necessity.

How Supplied.—Very few experiments have been made on the amount of inorganic nutrients demanded either by young or mature animals, although it has been fully proved that a lack of them may be a cause of backwardness in growth, or even be fatal. Experience shows, however, that such cases are rare, and it is only when the fodder consists largely of materials known to be poor in lime or phosphoric acid that their occurrence is to be apprehended.

Under such circumstances a lack of lime is easily supplied by a "lick stone" of chalk or soft limestone, or by the addition of chalk or leached ashes to the fodder. When a lack of phosphoric acid is suspected, the use of bone meal is commonly recommended. The bone should be ground exceedingly fine, and even then the danger that it may contain diseased bone is not excluded, though the latter would probably be reduced by the use of bone from which glue has been made, and which has consequently been cooked.

A safer material than bone meal is chemically prepared precipitated phosphate of lime, when obtainable.

Better than either of these methods, however, is the use of fodder containing more phosphoric acid. This may easily be brought about by the use of some bye-fodder which is rich in this substance, such as fish scrap or dried blood, oil cake, or the bye-products of the grains.

CHAPTER VII.

THE CALCULATION OF RATIONS.

In the foregoing chapters we have been chiefly occupied with a consideration of the quantities of digestible nutrients which are required in the food of farm animals for various purposes, and have only incidentally touched on the question of how these are to be supplied. In this chapter we shall consider the manner of compounding a ration which shall contain the quantities of digestible nutrients called for by a feeding standard.

When animals are pastured, or when they receive but a single kind of fodder, as good hay, for example, there is evidently no occasion for the use of a feeding standard; but when, as is usually the case in stall-feeding, the available coarse fodder is deficient in protein and must be supplemented by bye-fodder, a feeding standard can afford valuable aid in determining the proper proportions of the various feeding-stuffs.

As an example, we will take the feeding of milk cows according to Wolff's feeding standard, viz.:

Digestible protein	2.5	pounds.
" fat	0.4	"
" carbhydrates	12.5	"
Total dry matter	24.0	"
Nutritive ratio	1:5.4	

Suppose that there is available for the daily fodder of the cows, per 1,000 lbs. live-weight, twelve pounds of hay, six pounds of oat straw, and twenty pounds of mangolds, and that brewers' grains can be had cheaply. Plainly what we have to do is, first, to ascertain how much digestible matter the available amounts of coarse fodder and roots will furnish, and second, to calculate how much must be added to this ration to bring it up to the feeding standard.

We first need to know the percentages of digestible protein, carbhydrates, and fat contained in each of the feeding-stuffs, and for this purpose we must avail ourselves of the results obtained by others, since it is obviously impracticable to make direct digestion experiments. For this purpose we make use of tables of the composition and digestibility of feeding-stuffs, like those given in the Appendix, in which the results of all available analyses and digestion experiments are condensed.

The tables given in the Appendix are essentially those of Julius Kühn; they show both the *average* composition and digestibility of the common feeding-stuffs and also the observed *range of variation* in these respects. Wolff, in his table, gives directly the average percentage of digestible nutrients contained in each fodder, thus facilitating the calculation of rations. This convenience, however, is attained only by assuming a uniform composition and digestibility for each feeding-stuff, assumptions which, as we have seen, and as Kühn's tables show, are far from being true, particularly as regards coarse fodder. Moreover, comparatively few feeding-stuffs have been tested as to their digestibility, that of the others being only estimated. Under these circumstances the most rational method is to endeavor to form an estimate in each particular case of the amount of digestible matter likely to be present in the fodder. This method, though less simple than merely taking the average percentages of digestible ingredients from a table, is likely to give results corresponding more closely to the truth, when intelligently carried out, and has also the advantage of keeping prominently before the mind the approximate character of the calculation.

Two facts will serve to aid us in forming a judgment as to the amounts of digestible nutrients which a given fodder will furnish: first, the digestibility of a feeding-stuff depends largely on its chemical composition, and second, the composition of coarse fodder is quite variable, while that of the concentrated fodders is more constant.

Our first step, then, in the case supposed, is to form an estimate of the composition of the hay, straw, and roots which are to form the basis of the ration. By far the most satisfactory method of doing this is by the help of a partial analysis, and such analyses of feeding-stuffs might appropriately be undertaken by the Experiment Stations now beginning to be established in our midst. In the case of a coarse fodder, like hay or straw, determinations of water, protein, and crude fibre should be made; in concentrated fodders water and protein, and in some cases fat, should be determined. For the ash and fat of coarse fodders and the ash and crude fibre of concentrated fodders the average numbers may safely be taken, while subtracting the sum of the protein, crude fibre, fat, and ash from 100 will give the approximate amount of nitrogen-free extract. In this way the composition of the feeding-stuffs in question may be determined with sufficient accuracy for the purpose.

When it is not practicable to procure an analysis of the feeding-stuffs to be used, their composition must be estimated as well as may be by the aid of the table in the Appendix. This table shows the extremes of composition yet observed, and also gives the probable average composition. In using the table, it is to be remembered that in many cases the extreme numbers represent the composition of exceptional samples, and that the ordinary range of composition of the material under consideration may be considerably less than appears from the table. It is seldom that ordinarily good fodders will reach either the maximum or minimum of any ingredient, and the judgment of the feeder will be exercised in determining how great a variation from the average is to be expected in the particular case under consideration. To this end he will take into account the richness of the soil on which the fodder was grown, its stage of growth, and, in short, all those influences mentioned in Part II., Chapters II. and III., as affecting the composition of coarse fodder in particular. Under meadow hay and clover hay, in the table, Wolff's classification of these feeding-stuffs has been introduced. The "inferior" hay corresponds to that cut at an advanced stage of growth, or damaged by rain, or to the rank hay of low and shady places, and is characterized by a large percentage of crude fibre and a small percentage of protein. The better qualities of meadow and clover hay are those obtained by early cutting from a rich soil and careful curing without loss. The figures given by Wolff for the protein of these classes of hay are considerably higher than those that have been found for American hay of apparently equal quality and containing no more crude fibre. This fact must, of course, be borne in mind in using Wolff's figures.

In the case which we have selected for an example, we will suppose that by one or the other of the above methods we have found the composition of our feeding-stuffs to be approximately the following:

	Hay. Per cent.	Oat straw. Per cent.	Mangolds. Per cent.	Brewers' grains. Per cent.
Water	14	14	88	77
Protein	9	4	1	5
Fat	2	1	..	1
Nitrogen-free extract	43	33	9	11
Crude fibre	26	44	1	5
Ash	6	4	1	1
	100	100	100	100

We have now to estimate the percentage of each of the ingredients of these feeding-stuffs which is digestible. The mangolds, like all roots and tubers, we may assume to be wholly digestible. For concentrated fodders we may in most cases assume the average digestion coefficients, both because the digestibility of these fodders varies less than that of coarse fodder, and because fewer experiments have been made on them. On brewers' grains there have been no experiments, but our table gives estimates of their digestibility, and these we accept provisionally in the absence of anything more exact.

Of the non-nitrogenous ingredients of the coarse fodder, the fat is present in so small quantity that the assumption of average digestibility can introduce no serious error, while, as we have seen (p. 250), the nitrogen-free extract of a coarse fodder represents approximately the total quantity of digestible carbhydrates which it contains. This fact, though only true in a general way, probably forms as accurate a basis for computations of digestibility as is furnished by the use of digestion coefficients, especially if account be taken of the fact that the total digestible carbhydrates are likely to exceed the nitrogen-free extract in coarse fodder which is rich in protein, and to fall short of it in feeding-stuffs having a low percentage of protein.

There remains to be considered only the protein of the coarse fodder, and just this substance shows the greatest variations of digestibility. In general it is most digestible in those feeding-stuffs which contain most protein and least crude fibre, that is, in young and tender fodder, while in that which is old and woody or of coarse texture it is generally less digestible.

In the case above supposed both the hay and straw are of nearly average composition, and we therefore assume average digestion coefficients for their protein, viz., 57 for that of the hay and 38 for that of the straw.

A simple computation now shows us that 100 pounds of each of our four feeding-stuffs will furnish the following amounts of *digestible* nutrients:

	Hay. Lbs.	Oat straw. Lbs.	Mangolds. Lbs.	Brewers' grains. Lbs.
Protein	5.13	3.51	1	4.25
Carbhydrates...........	43.00	33.00	10	16.00
Fat....................	0.92	0.30	..	0.80

From these data we can easily calculate that the quantities of hay, straw, and mangolds which we have assumed to be available per day and 1,000 lbs. live-weight, together with twenty pounds of brewers' grains, will furnish the cows with the following quantities of digestible protein, carbhydrates, and fat:

	Total dry substance. Lbs.	DIGESTIBLE.		
		Albuminoids. Lbs.	Carbhydrates. Lbs.	Fat. Lbs.
12 lbs. hay.............	10.32	0.62	5.16	0.11
6 lbs. oat straw.........	5.16	0.09	1.98	0.02
20 lbs. mangolds........	2.40	0.20	2.00	....
20 lbs. brewers' grains ..	4.60	0.85	3.20	0.16
Total..............	22.48	1.76	12.34	0.29

This ration falls short of the standard by about three-quarters of a pound of digestible protein. This must evidently be supplied by some nitrogenous bye-fodder, such as oil cake, fish, etc. Taking cotton-seed meal as an illustration, we find that the addition of two and one-half pounds of this feeding-stuff to the above ration, supposing the meal to have the average composition of the American article, and to be of average digestibility, will bring it up to the desired standard.

	Total dry substance. Lbs.	DIGESTIBLE.		
		Albuminoids. Lbs.	Carbhydrates. Lbs.	Fat. Lb.
Total as above	22.48	1.76	12.34	0.29
2.5 lbs. cotton-seed meal.	1.96	0.79	0.42	0.13
Total..............	24.44	2.55	12.76	0.42
Standard...........	24.00	2.50	12.50	0.40

An exact correspondence with the standard need not be sought, and, indeed, it is evident from the foregoing paragraphs that such a correspondence, if attained, would be more apparent than real. The amount of non-nitrogenous nutrients may vary more than that of the protein, and the exact quantity of fat, in particular, is a matter of no special importance, provided too much is not fed. As a general rule, it is advisable to give too much rather than too little protein, both to ensure a sufficient supply of this important nutrient and for the reasons stated on pp. 280–283.

In practice, of course, regard must be had to individual peculiarities of the animals, as well as to differences in weight. The most satisfactory plan would probably be to weigh out each day a sufficient supply for all the cattle which receive the ration, and to distribute this amount among the animals according to their requirements. As a matter of course the animals must be carefully observed, and their supply of food modified according to the indications thus obtained. The feeding standards, as already said, are not inflexible rules, to be blindly followed, but guides and indications which must be intelligently adapted to local and individual circumstances.

The example given above serves to illustrate the manner of calculating rations in accordance with a feeding standard. The chief points there given may be summed up in the following

Rules for the Calculation of Rations.

1. The composition of the fodders used is either ascertained by analysis or estimated from the table of the composition of feeding-stuffs.

2. Tubers and roots are considered to be wholly digestible.

3. For the concentrated fodders, the average digestion co-efficients are employed in most cases.

4. The digestible carbhydrates of the coarse fodders are considered to be equal to the total nitrogen-free extract.

5. The digestibility of the protein of the coarse fodder is estimated from the composition of the latter, it being the greater the less crude fibre and the more protein the feeding-stuff contains.

6. By multiplying the percentage of each ingredient of the fodders by its digestion coefficient, the percentage of digestible matters in each feeding-stuff is obtained, the digestible nitrogen-free extract and digestible crude fibre being added together as carbhydrates.

7. From the data thus obtained we calculate, first, the quantities of digestible protein, carbhydrates, and fat in the amounts of fodder available, and second, what addition of bye-fodder must be made to them to bring the ration up to the feeding standard.

8. If the dry matter of the tubers or roots entering into the ration does not exceed one-eighth that of the dry matter of the remaining fodder no deduction is made from the above figures. If, however, the dry matter of the roots or tubers exceeds this proportion, a deduction must be made from the amount of digestible protein of the ration as calculated, in the proportions indicated on page 285.

These corrections may be considered sufficient when the coarse fodder consists chiefly of hay, and ample when the addition consists chiefly of roots and not of potatoes. On the contrary they are hardly sufficient when the ration contains much straw and potatoes. The depression of the digestibility, however, is decidedly diminished when the nutritive ratio of the whole ration, and especially that of the bye-fodder, is a narrow, or at least medium one (1 : 5 to 6).

9. If it is desired to test the correspondence of the calculated amount of digestible protein with that really present, the latter may also be calculated by Stohmann's formula, page 256.

APPENDIX.

Of the tables contained in the Appendix, I. and II. are essentially those of Julius Kühn (*Mentzel & v. Lengerke's Landw. Kalender*, 1880), and III. and IV. are from Wolff.

As regards numerical accuracy, there is little difference between Kühn's tables and Wolff's, the averages of the former being mostly identical with those of the latter. As will be seen, Kühn's contain, in addition to the average composition and digestibility, the range of variation hitherto observed in these respects, and thus afford a better means of estimating the composition of particular feeding-stuffs. (Compare page 467, and also the remarks in the preface.)

In Table I. Wolff's classification of meadow hay and clover hay has been introduced, and averages of all available analyses of American feeding-stuffs have been given. For the latter the author is indebted to the valuable compilation of Dr. E. H. Jenkins, published in the "Report of the Connecticut Agricultural Experiment Station" for 1879. In Table II. Wolff's classification of hay has also been introduced, and likewise the results recently obtained by Wolff in experiments on the horse (*Landw. Jahrbücher*, VII., Supplement I.). In regard to the manner of using the tables, compare Chapter VII., of Part III.

In all the tables "protein" signifies nitrogen × 6.25; that is, it includes gelatin, amides, and all other forms of non-protein.

TABLE I—COMPOSITION OF FEEDING-STUFFS.

	TOTAL DRY MATTER.			PROTEIN.			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.			ASH.
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	
GREEN FODDER.																
Pasture grass	12.4	48.1	25.0	1.6	6.0	3.0	0.3	1.5	0.8	3.5	22.8	13.1	3.12	17.0	6.0	2.1
Italian rye grass	24.9	28.3	26.6	2.6	4.6	3.6	....	....	1.0	11.3	12.9	12.1	4.8	9.4	7.1	2.8
Timothy	30.0	31.9	31.0	2.0	3.4	2.7	0.4	1.1	0.8	13.6	16.3	14.9	8.0	13.5	10.5	2.1
Various grasses (in blossom)	22.0	40.5	29.2	1.9	4.0	2.6	0.3	1.1	0.70	8.4	15.4	11.7	7.0	16.3	12.1	2.1
Red clover	13.6	31.9	19.8	2.2	6.2	3.6	0.4	1.6	0.70	4.2	15.1	8.5	3.4	11.0	5.6	1.4
White "	16.4	20.3	19.8	3.5	4.5	4.0	0.8	0.9	0.85	7.2	9.8	8.0	5.2	6.0	5.6	1.4
Incarnate clover	17.4	18.5	18.0	2.7	3.0	2.8	0.6	0.9	0.70	6.1	7.4	6.7	3.8	7.5	6.2	1.6
Alsike or Swedish clover	13.0	23.3	18.0	2.4	5.7	3.3	0.6	0.7	0.65	5.1	8.4	6.3	3.6	16.4	6.0	1.8
Kidney vetch (*Anthyllis vulneraria*)	15.1	23.8	19.0	2.4	2.8	2.6	0.4	0.6	0.50	7.2	11.9	9.2	3.1	7.6	5.5	1.2
Medick (*Medicago lupulina*)	20.0	23.3	21.0	3.2	5.7	3.5	0.8	0.9	0.85	8.0	10.0	8.2	6.0	7.6	6.9	1.5
Lucerne	16.5	30.1	24.7	2.8	7.3	4.5	0.5	0.9	0.70	6.0	14.4	8.4	3.5	13.4	9.3	1.8
Esparsette	20.0	23.4	21.5	3.2	4.3	3.5	0.6	0.9	0.70	8.2	10.8	8.5	5.8	12.9	7.6	1.2
Serradella	14.2	20.0	18.0	2.6	3.6	3.0	0.4	1.1	0.7	5.1	8.9	7.0	5.0	8.1	5.7	1.6
Lupines	10.6	16.1	14.3	2.4	4.2	3.1	0.2	0.4	0.30	4.0	7.3	6.2	1.4	5.1	4.0	0.7
Beans (beginning to blossom)	....	....	12.7	....	....	2.8	....	....	0.30	....	....	5.1	....	....	3.5	1.0
Vetches	15.7	19.4	18.0	2.7	4.7	3.7	....	....	0.60	4.5	12.7	6.1	3.9	10.0	6.0	1.6
Peas	13.3	23.9	18.5	3.2	3.9	3.5	....	....	0.60	4.6	10.5	7.6	3.0	7.7	5.4	1.4
Oats	13.5	23.0	18.2	1.8	3.1	2.4	0.5	0.6	0.55	5.1	8.8	7.0	4.6	7.0	6.5	1.7
Rye	20.4	33.5	24.0	3.1	3.6	3.3	0.6	0.9	0.75	6.7	14.0	10.4	7.3	8.6	7.9	1.6
Maize fodder	13.2	23.2	16.0	0.9	2.2	1.4	0.2	0.8	0.50	5.8	15.3	8.4	3.0	5.9	4.7	1.0
Maize fodder (American)	7.09	19.26	13.14	0.8	1.5	1.1	0.1	0.3	0.2	3.2	9.2	6.5	1.9	5.9	4.1	1.2
Sorghum	15.9	16.0	23.8	1.7	5.8	2.5	0.7	1.5	1.20	8.4	19.2	12.2	4.6	8.5	6.8	1.1
Hungarian grass (Golden millet	19.0	37.1	28.7	2.5	5.9	4.4	0.8	1.5	1.1	6.0	16.2	12.1	4.6	11.6	9.2	1.9
Spurry (*Spergula arvensis*)	10.2	24.6	20.8	0.9	4.3	2.9	0.5	1.1	0.70	4.3	10.8	8.8	3.5	8.6	6.1	2.3
White mustard	....	....	12.6	....	....	3.3	....	....	....	....	....	3.5	....	....	3.8	2.0
Green rape	13.0	15.0	14.0	2.7	3.1	2.9	....	....	0.6	3.5	3.9	3.7	3.6	15.0	5.2	1.6
Cabbage	5.5	20.2	14.3	0.9	4.7	2.5	0.4	1.0	0.7	1.5	12.9	7.1	0.5	5.6	2.4	1.6

Beet leaves...	8 0	13.2	10.7	1.4	3.2	2.2	0.1	1.0	0.4	2.1	5.9	4.8	0.9	2.4	1.5	1.8
Turnip leaves..................	....	....	11.6	...	2.8	2.1	....	....	0.5	....	....	5.1	....	....	1.6	2.3
Kohlrabi "	13.3	15.0	14.3	2.4	....	2.6	...	....	0.8	8.3	9.0	8.4	0.8	1.4	1.1	1.4
Carrot "	17.8	23.5	20.3	3.2	3.8	3.5	0.6	1.0	0.8	7.0	12.9	9.2	3.0	3.4	3.2	3.6
Parsnip "	....	...	16.9	....	....	1.8	....	....	0.4	....		9.9	....	....	2.2	2.6
Buckwheat	12.5	17.5	15.0	1.5	3.2	2.3	0.5	0.8	0.7	5.1	7.4	6.3	4.2	4.4	4.3	1.4
Artichoke tops (green)	20.0	44.7	32.0	2.5	3.3	2 9	0.16	0.9	0.8	9.8	25.8	17.8	1.0	8.0	5.7	4.8
Potato tops.......	....	....	22.0	....	....	2.3	....	....	1.0	....	....	9.7	....	....	6.0	3.0
Sweet clover (*Meililotus alba*)...	....	....	12.5	....	....	2.9	....	....	0.4	....	....	3.5	....	....	3.6	2.1
Green leaves (of trees)..........	34.2	45.0	38.9	2.8	8.0	5.2	....	....	1.5	5.2	33.1	15.2	6.0	22.9	13.0	4.0
HAY.																
Meadow hay......................	78.3	90.2	85.7	5.8	19.4	9.5	1.2	5.6	2.3	22.6	50.7	40.3	19.7	39.9	27.1	6.5
" " (Wolff's classification)... Very good*.	....	....	100.0	11.8	25.1	14.5	1.6	5.9	3.6	28.1	52.8	46.2	17.4	37.0	26.8	8.9
Medium*...	....	....	100.0	7.1	11.2	10.0	2.2	4.4	3.1	45.3	54.7	49.4	24.1	34.8	30.0	8.2
Inferior*...	....	....	100.0	7.1	11.2	9.4	2.2	3.6	2 7	45.3	50.2	48.1	30.0	34.8	33.0	6.9
Hay of cultivated grasses........	...	...	85 7	5.2	14.8	9.5	1.7	3.2	2.6	32.6	48.6	39.1	16.9	34.0	28.7	5.8
American hay. *Timothy*	85.7	87.5	86.5	4.9	8.4	6.2	1.1	2.0	1.7	43.3	48.1	45.8	25.3	32.8	28.9	3.9
" *and red top*........	....	....	85.7	6.0	9.0	7.6	1.5	2.5	2.0	39.2	46.9	44 1	24.7	28.5	26.5	5.5
" " *blue grass*.. ..	....	....	85.7	....	...	7.0	....	....	1.7	....	....	45.4	....	....	26.9	4.7
Mixed grasses†..............	....	....	85.7	6 0	9.0	7.3	1.4	2.5	1.8	39.2	47.3	44.9	24.7	28.5	26.7	5.1
Containing clover...........	....	....	85.7	9.0	14.4	10.9	1.5	3.1	2.3	42.1	44.9	43.0	19.7	28.2	24.1	5.4
Low meadow hay..........	85.7	93.6	90.0	4.6	10.4	7.4	0.7	3.6	2.2	39.8	55.2	43.8	21.4	40.0	30.8	5.8
Salt marsh hay............	81.4	92.8	89.3	4.3	7.8	6.1	1.7	3.1	2.4	34.1	48.5	41.3	27.6	37.9	31.9	7.6
Rowen	79.8	88.2	85.7	8.4	18.5	11.7	2.3	6.8	3.1	33.3	49.7	42.3	19.0	20.7	22.0	6.6
Clover hay.......................	77.1	90.0	83.3	7.2	15.8	11.0	1.2	5.5	3.2	22.3	39.7	32.9	19.5	43.0	29.9	6.3
Clover hay (American).........	....	....	85.7	8.9	12.2	11.0	1.5	2.1	1.8	41.0	42.0	41.4	23.8	27.2	25.1	6.4
Clover hay (Wolff's classification).. Excellent*..	....	....	100.0	....	...	18.3	....	....	3.8	....	....	42.8	....	....	26.6	8.4
Very good*.	....	....	100.0	....	....	16.2	....	....	3.5	....	....	44.4	....	..	28.7	7.2
Average*...	...	....	100.0	....	....	14.3	....	....	2.9	....	.. ..	46.3	....	....	30.5	6.3
Clover hay damaged by rain. ...	84.0	85.5	....	14.0	15.8	. ..	....	3.3	....	9.8	23.4	....	37.2	52.7	....	6.6
Hay of pure red clover..........	78.5	87.1	84.0	7.6	18.3	13.4	1.4	5.1	3.2	15.2	48.1	36.4	18.8	48.1	25.4	5.6
White clover hay	78.4	90.2	83 3	7.7	17.0	14.9	1.4	3.7	3.5	30.8	41.3	33.9	18.8	25.6	22.5	8 5
Alsike or Swedish clover hay	83.3	85 6	84.0	9.1	24.9	14.8	....	....	3.3	21.2	41.2	29.7	16.6	48.8	30.1	6.1
Hay of kidney vetch (*Anthyllis vulneraria*)....... ...	83.3	89 5	84.9	7.4	13.8	9.7	1.2	3.3	2.4	35.1	43.9	38.4	17.0	32.0	28.4	6.0
" medick (*Medicago lupulina*)..	83.3	89.5	84.8	11.8	21.1	17.1	3.2	3.3	3.25	30 8	33.2	32 0	23.1	28.0	26.1	6.3
" lucerne	80.8	87.5	83.8	13.1	19.7	14.4	2.3	3.8	2.5	20 0	34.8	27.9	19.3	40.0	33.0	6.0
" esparsette..........	83 3	88 2	85.1	12.8	17.1	13.3	....	....	2.5	34.2	34.7	34.5	27.1	30.9	29.0	5 8
" incarnate clover	82.8	85.7	84 0	11.5	14.0	12.7	....	....	3.0	27.1	32.7	30.2	27.9	33.8	31.2	6.9

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* Calculated to water-free basis.

† Including the preceding two.

TABLE I.—(*Continued.*)

	TOTAL DRY MATTER.			PROTEIN.			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.			ASH.
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	
HAY.																
Hay of sweet clover (*Mellilotus alba*)	85.7	88.0	86.4	13.6	19.9	15.8	2.7	3.0	2.9	24.0	28.5	26.8	24.7	37.0	32.6	8.3
" serradella	83.3	85.7	85.0	14.6	15.8	15.2	1.5	1.9	1.7	27.7	35.5	31.6	26.1	33.9	29.3	7.2
" yellow lupine	74.1	90.9	86.1	6.0	23.5	16.0	1.1	2.9	2.2	28.1	31.2	29.5	23.0	48.3	32.6	5.8
" spurry (*Spergula arvensis*)	83.3	87.5	86.0	7.8	14.7	11.8	1.7	3.2	2.7	26.0	44.2	34.2	20.2	35.1	27.8	9.5
" vetches	83.3	85.7	85.1	14.2	20.4	17.6	2.1	2.5	2.3	28.5	32.8	29.7	23.5	29.5	26.5	9.0
" fodder rye	85.7	90.5	88.1	9.8	10.4	10.1	2.8	2.9	2.85	30.1	44.5	37.3	23.1	40.3	31.7	6.2
" Hungarian grass (golden millet)	83.7	90.1	86.6	7.0	14.6	10.8	2.0	2.4	2.2	33.3	41.2	38.5	26.8	34.5	29.4	5.7
" Hungarian grass (*American*)	....	....	83.3	5.7	10.7	7.6	1.3	1.7	1.5	34.9	42.4	40.3	27.8	28.9	28.1	5.8
" Hungarian grass (*American*, mature samples)	....	....	83.3	....	....	5.9	....	....	1.4	....	....	42.1	....	....	28.1	5.8
Leaves of trees (dry)	84.0	95.0	89.9	6.0	15.1	10.6	3.0	4.2	3.6	43.8	68.2	55.4	11.3	16.3	14.5	5.8
Artichoke tops "	....	....	93.3	....	....	11.8	....	....	0.7	....	....	69.3	....	....	4.7	6.8
Potato tops (dry)	85.0	95.3	90.0	5.7	12.9	9.4	1.2	3.6	2.4	33.0	38.6	34.6	22.7	36.6	32.0	11.6
"Brown hay" of chiccory leaves.	58.8	85.0	68.7	9.2	13.0	11.1	2.3	3.3	2.8	25.2	36.6	30.9	8.2	11.8	10.0	13.9
"Sour hay" of root tops	20.0	26.8	23.4	0.94	3.0	1.9	0.75	1.2	1.0	8.6	9.0	8.8	2.0	2.7	2.3	9.4
" " maize (ensilage)	11.7	23.0	16.5	0.7	1.8	1.2	0.2	1.9	0.9	4.5	9.2	8.0	2.1	9.6	5.3	1.1
" " red clover	....	....	20.8	....	....	4.2	....	....	2.2	....	....	6.4	....	....	5.9	2.1
" " half-ripe lupines	....	....	20.1	....	....	3.1	....	....	0.8	....	....	6.5	....	....	6.8	2.9
" " esparsette*	....	....	16.7	....	....	3.4	....	....	1.0	....	....	5.1	....	....	6.9	1.3
"Brown hay" of clover	83.8	88.2	86.0	16.2	17.2	16.7	1.6	3.2	2.4	31.3	35.4	33.3	22.2	28.6	25.4	8.2
" " grasses	....	....	85.7	....	....	8.6	....	....	2.9	....	....	45.5	....	....	22.4	6.3
" " maize*	....	....	20.7	....	....	1.0	....	....	1.1	....	....	10.1	....	....	7.0	1.5
" " esparsette*	....	....	47.5	....	....	9.8	....	....	2.3	....	....	16.7	....	....	15.4	3.3

* Wolff.

STRAW.																
Wheat straw	74.0	91.9	85.7	1.4	5.6	3.1	0.6	2.0	1.2	26.7	44.4	37.5	28.9	52.6	40.0	3.9
Spelt "	....	....	85.7	2.0	2.5	2.3	1.4	1.5	1.45	28.7	31.8	30.3	45.0	48.0	46.5	5.2
Rye "	81.4	89.7	85.7	1.5	4.6	3.0	1.1	2.5	1.3	23.4	44.5	33.3	30.1	54.9	44.0	4.1
" " (*American*, one analysis)	....	....	87.5	....	....	6.9	....	....	2.7	....	....	35.7	....	....	34.2	8.0
Barley straw	82.5	89.1	85.7	1.9	5.4	3.4	1.1	2.04	1.4	18.2	45.5	34.7	34.4	54.0	41.8	4.4
" " with clover	84.4	90.3	85.7	6.0	9.1	6.5	1.7	2.3	2.0	28.3	34.7	32.5	37.0	39.7	38.0	6.7
Oat straw	78.8	89.7	85.7	1.3	7.0	4.0	1.0	5.1	2.0	24.9	48.9	35.6	30.0	50.2	39.7	4.4
" " (*American*, one analysis)	....	....	87.5	....	....	2.3	....	....	1.0	....	....	26.4	....	....	56.0	1.8
Stover. Maize straw	....	....	86.0	....	....	3.0	....	....	1.1	....	....	37.9	....	....	40.0	4.0
" (*American*)*	....	....	100.0	7.3	7.6	7.5	....	....	1.8	52.5	56.4	54.4	30.0	33.1	31.5	4.8
Pea straw	82.6	88.1	85.7	4.8	10.1	7.3	1.5	3.3	2.0	22.8	39.8	32.3	33.6	51.8	39.2	4.9
Vetch "	83.3	87.5	85.7	6.2	7.5	7.0	....	....	2.0	18.3	37.9	28.1	30.8	53.1	42.6	6.0
Lentil "	....	....	84.0	....	....	14.0	....	....	2.0	....	....	27.9	....	....	33.6	6.5
Bean "	78.0	85.5	82.5	3.3	16.4	9.9	0.7	2.2	1.5	16.9	33.8	31.8	25.8	41.7	33.5	5.8
Lupine straw	85.8	89.7	87.4	4.9	6.2	5.5	1.1	1.5	1.3	33.2	35.6	34.3	41.8	43.5	42.5	5.8
Cow pea vines (fresh)	....	....	27.2	....	....	1.9	....	....	0.2	....	....	7.8	....	....	15.3	2.0
Rape straw	78.5	87.8	84.0	2.5	4.6	3.5	1.0	5.7	1.5	31.3	36.0	34.2	37.5	40.9	39.5	5.3
Buckwheat straw	84.5	90.3	87·9	3.1	5.5	4.1	1.3	1.6	1.4	29.9	37.1	32.9	35.3	51.8	44.3	5.2
" " (*American*)	89.6	89.7	89.6	3.3	4.4	3.9	1.4	1.7	1.5	32.1	34.5	33.3	44.9	46.8	45.8	5.1
CHAFF, HULLS, ETC.																
Wheat	78.3	90.2	85.7	5.8	19.4	9.5	1.2	5.6	2.3	22.6	50.7	40.3	19.7	39.9	27.1	6.5
Spelt	79.8	88.2	85.7	8.4	18.5	11.7	2.3	6.8	3.1	33.3	49.7	42.3	19.0	30.7	22.0	6.6
Rye	....	....	85.7	3.5	3.7	3.6	1.2	1.8	1.4	28.0	31.5	29.7	41.5	46.6	43.5	7.5
Oat	85.7	87.4	86.4	3.7	7.0	4.9	1.3	1.5	1.4	28.2	43.2	37.4	25.9	35.1	31.7	11.0
Pea	85.7	87.6	86.0	7.2	15.8	10.3	1.0	4.7	2.5	30.0	36.6	34.0	22.4	41.5	32.0	7.2
Vetch	84.9	87.5	85.7	7.2	15.7	10.2	1.0	2.0	1.5	20.5	42.3	32.7	22.7	49.6	33.0	8.3
Bean	82.0	87.5	85.0	10.0	11.3	10.6	1.0	2.0	1.5	27.5	34.0	30.3	33.0	37.5	35.2	7.4
Lupine	85.0	89.9	87.5	2.5	8.0	4.5	0.6	2.5	1.8	32.8	49.8	43.8	28.2	45.2	34.5	2.9
Flax	....	....	88.8	....	....	2.7	....	....	1.1	....	....	32.6	....	....	45.2	7.2
Rape	82.0	93.5	87.8	3.0	5.4	4.0	1.5	3.1	1.8	34.9	48.7	38.8	30.9	43.6	36.7	6.5
White clover	....	....	88.5	....	....	18.3	....	....	3.1	....	....	36.8	....	....	22.4	7.9
Maize cob	....	....	86.0	....	....	1.4	....	....	1.4	....	....	42.6	....	....	37.8	2.8
" " (*American*)	85.6	92.8	90.8	1.2	2.7	2.2	0.1	0.9	0.4	45.3	59.6	54.9	29.8	38.3	32.0	1.3
TUBERS AND ROOTS.																
Potato	18.3	33.5	25.0	1.0	4.4	2.0	0.04	0.8	0.3	15.7	26.6	20.7	0.27	2.7	1.1	0.9
Artichoke	16.5	20.9	19.6	1.3	2.5	2.0	0.1	0.5	0.3	13.7	16.2	15.0	0.5	2.7	1.3	1.0

* Reduced to water-free basis. Field cured, it contains 27 to 37 per cent. of water.

TABLE I.—(*Continued.*)

	TOTAL DRY MATTER.			PROTEIN.			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.			ASH.
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	
TUBERS AND ROOTS.																
Mangolds	7.4	24.6	12.0	0.55	2.6	1.1	0.05	0.6	0.1	5.2	13.8	9.1	0.6	4.5	0.9	0.8
Sugar beets	10.2	23.7	18.5	0.6	2.8	1 0	0.07	0.3	0.1	10.1	17.9	15.4	0.9	3.4	1.3	0.7
Rutabagas	8.9	16.2	13.0	0.7	1.7	1.3	..	....	0.1	7.1	10.1	9.5	....	....	1.1	1.0
" (*American, one analysis*)	....	....	12.9	....	....	1.1	....	....	0.1	....	....	9.1	....	....	1.2	1.4
" fermented	....	....	15.4	....	....	1.4	....	....	0.1	....	....	8.8	....	....	2.3	*2.8
Carrots	10.1	20.8	14.1	0.5	2.4	1.3	0.2	0.8	0 25	5.9	15.5	9.6	0.7	3.4	1.9	1.0
Turnips	7.1	13.9	8.5	0.6	1.8	1.0	0.1	0.2	0.15	3.7	10.9	5.8	0.3	1.0	9.7	0.8
Parsnips	....	....	11.7	....	....	1.6	....	....	0 2	....	....	8.2	....	....	1.0	0.7
Sweet potato (*American*)	26.6	34.0	30.3	0.5	1.3	0.9	....	....	0.3	23.0	30.0	26.3	1.0	2.5	1.7	1.1
Yam (*American*)	....	....	28.8	....	....	2.1	....	....	0.2	....	....	25.2	....	....	0.7	0.6
GRAINS AND FRUITS.																
Wheat	81.3	90.0	85.7	8.2	24.1	13.2	0.7	2.7	1.6	60.2	75.3	66.2	0.7	8.3	3.0	1.7
Winter wheat (*American*)	86.8	92.5	89.1	8.4	14.5	11.7				71.3	81.7	75.7				1.7
Spring " "	88.9	92.1	91.0	8.1	15.4	12.7				72.9	82.4	76.5				1.8
Spelt	84.7	93 0	87.9	9.1	14.5	11.0	1.4	3.0	2.3	52 8	68 2	63.9	2.3	17.0	7.7	3.0
Rye	81.7	91.4	85.7	7.9	17.4	11.4	0 9	2.8	1.7	62.5	72.4	67.8	1.1	6.7	3.0	1.8
Winter rye (*American*)	....	....	91.3	....	....	12.1	....	....	2.1	....	....	73.9	....	....	1.4	1.8
Barley	79.1	91.7	86.2	6.2	18.3	11.2	1.0	3.2	2.1	56.1	74.7	65.5	2.2	10.8	5.2	2.2
" (*American*)	....	....	92.8	....	....	13.2	....	....	3.1	....	....	73.0	....	....	1 6	1.9
Oats	83.6	92 4	86.3	6.3	18.5	12.0	4.4	7.3	6.0	48 0	71.8	56.6	4.1	16.1	9.0	2.7
" (*American*)	87.6	88 8	88.2	8.0	11.5	9.8	4.7	5.1	4.9	57 1	59 0	58.0	12.2	12.9	12.5	3.0
Maize	77.6	91.8	87.3	5.8	15.1	10.6	1.5	9.2	6.5	52.4	72.7	65.7	1.3	8.5	2.8	1.7
" *sweet corn* (*American*)	89.1	94 0	91.4	10.2	14.4	12.1	5.3	9.3	8.0	63.1	72.4	67.4	1.5	2.8	2.0	1.9
" *flint* " "	84.9	93.4	89.4	7.9	13.7	10.7	3.9	7.1	5.2	66.1	74.5	70.4	0.8	2.7	1.6	1.5

* Including 2.0 per cent. of sand.

Maize, *dent corn* (*American*)....	85.6	93.3	88.9	8.1	11.8	10.5	4.0	6.3	4.8	66.3	74.5	70.2	1.3	2.5	1.9	1.5
Common millet (*Panicum milliaceum*)........................	86.0	86.9	86.5	10.9	14.5	12.7	3.0	3.7	3.3	56.9	59.1	58.0	6.4	13.1	9.5	3.0
Golden millet (*Setaria Italaca*)..	....	....	86.6	....	....	9.6	....	....	4.0	....	....	58.6	....	....	11.6	2.8
Rice....................................	....	....	85.2	....	....	7.5	....	....	0.5	....	....	76.0	....	....	0.9	0.3
Buckwheat	84.6	96.2	86.8	8.6	11.2	10.1	0.9	2.7	1.5	52.1	62.6	59.5	6.4	40.2	15.0	1.8
Field beans........................	80.3	88.3	85.9	21.4	28.2	25.1	1.2	2.5	1.6	42.8	55.4	46.7	3.7	12.6	9.4	3.1
Peas....................................	77.9	91.1	86.8	18.6	27.1	22.4	0.6	5.3	3.0	41.9	59.6	52.6	1.9	9.2	6.4	2.4
Vetches	84.2	91.0	86.4	26.5	29.1	27.5	1.2	3.0	2.3	44.9	51.8	47.2	3.5	7.2	6.7	2.7
Lentils................................	85.5	88.8	87.5	22.8	25.4	23.8	1.0	2.6	2.1	49.4	57.2	53.9	3.3	6.9	4.9	2.8
Yellow lupines..	82.4	90.6	87.2	28.3	43.3	35.4	3.7	7.9	5.3	20.2	36.4	29.2	11.4	17.5	13.8	3.5
Blue "	78.0	88.0	85.0	21.7	35.9	28.0	4.6	8.8	5.3	20.7	43.8	36.6	8.9	13.9	11.9	3.2
Cow peas (*American*)	79.2	80.8	80.0	20.1	23.0	21.6	1.3	1.4	1.3	48.1	50.5	49.3	4.3	5.0	4.7	3.1
Spurry...............................	....	....	91.3	....	....	18.0	....	....	11.5	....	....	53.7	....	....	5.7	2.4
Serradella..........	86.9	92.2	91.3	17.8	25.6	22.0	5.0	9.5	7.3	31.1	43.8	37.5	16.1	29.4	21.1	3.4
Flax seed........................	87.7	93.2	88.2	20.0	28.5	21.7	21.7	39.0	35.6	9.0	35.7	19.6	3.2	18.0	7.9	3.4
Rape "	85.2	92.9	86.2	13.0	27.4	19.4	36.0	55.0	42.5	7.4	13.0	10.4	5.3	15.2	10.0	3.9
Hemp "	....	....	87.8	....	....	16.3	....	....	33.6	....	....	21.3	....	....	12.1	4.5
Sunflower seed................	89.3	93.8	92.0	12.7	13.3	13.0	21.0	34.7	23.6	....	....	23.9	....	....	28.5	3.0
Cotton "	91.1	92.3	91.9	22.75	22.8	22.8	20.3	30.3	29.8	7.6	15.4	11.5	16.0	24.7	20.3	7.5
Palm nuts (seeds of oil palm)....	90.9	93.9	92.3	7.9	8.9	8.4	48.9	49.5	49.2	25.6	28.1	26.9	5.5	6.5	6.0	1.8
Peanuts.............................	....	....	93.7	....	....	28.2	....	....	41.2	....		7.2	....	....	13.9	3.2
Acorns, with shell (fresh)	44.0	58.5	49.3	2.0	2.6	2.2	1.5	2.3	2.0	33.4	36.5	34.7	4.3	10.4	9.4	1.0
" without shell (dry)......	80.0	88.6	85.6	5.0	6.3	5.6	3.6	5.4	4.1	64.8	72.0	69.2	4.6	5.9	5.1	1.6
Horse chestnuts, with shell (fresh)	....	....	50.8	....	....	6.4	....	....	1.4	....	....	38.9	....	....	2.9	1.2
" " " " (dry)	....	....	81.2	....	....	6.9	....	....	3.2	....	....	65.3	....	....	4.0	1.8
Chestnuts, without shell (fresh).	50.8	51.3	51.0	3.0	3.3	3.1	1.75	2.5	2.1	42.7	43.7	43.2	....	....	0.8	1.8
Apples and pears................	13.4	18.6	16.9	0.2	0.5	0.4	....	....	....	10.2	13.3	11.8	2.9	5.1	4.3	0.4
Apples (*American*).......... ...	14.0	17.8	16.8	0.2	0.3	0.2	0.3	0.5	0.4	11.3	15.8	15.0	0.9	1.0	0.9	0.3
Pumpkin..............................	5.4	21.1	10.9	0.1	1.3	0.6	....	....	0.1	1.5	13.9	6.5	1.0	5.9	2.7	1.0
" *flesh* (*American*).......	5.4	7.6	6.5	0.9	1.0	0.9	....	....	0.1	3.1	4.8	3.9	0.9	1.1	1.0	0.6
" *rind* "	12.0	15.6	13.8	2.6	2.9	2.8	....	....	0.5	4.7	6.8	5.7	3.0	3.9	3.4	1.4
" *seeds and stringy parts* (*American*)..................	22.2	24.1	23.1	5.7	6.3	6.0	6.7	7.1	6.9	4.3	5.2	4.8	3.7	4.1	3.9	1.5
Squash, flesh (*American*)........	10.4	11.7	11.9	0.7	1.1	0.9	....	....	0.2	7.1	12.0	9.1	0.9	1.2	1.0	0.7
" *rind* "	14.4	21.0	18.0	2.8	2.9	2.8	0.6	0.8	0.7	6.4	12.4	10.1	1.0	3.9	3.2	1.2
" *seeds and stringy parts* (*American*)..........	16.7	33.3	25.9	4.0	6.1	5.3	3.6	7.8	6.3	6.2	11.8	8.6	2.1	6.2	4.3	1.4
FLOUR AND MEAL.																
Wheat flour........................	84.5	90.5	86.4	7.8	15.6	11.3	1.0	1.6	1.2	68.9	74.3	72.3	0.2	1.2	0.8	0.8
" " (*American*)..........	86.5	90.9	89.2	8.6	13.6	10.9				73.4	80.7	77.7				0.6

TABLE I.—(*Continued.*)

	TOTAL DRY MATTER.			PROTEIN.			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.			ASH.
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	
FLOUR AND MEAL.																
Rye flour	85.4	86.0	85.8	9.1	15.9	11.7	1.6	2.5	2.0	67.0	74.5	69.3	1.0	1.5	1.2	1.6
Barley meal	85.0	86.0	85.5	10.2	14.3	13.0	....	....	2.2	62.5	69.8	67.0	....	....	....	2.0
" " (*American*)	....	....	90.2	....	....	12.7	....	....	3.2	....	....	63.5	....	....	7.0	3.8
Oatmeal	87.7	88.3	88.0	15.5	19.5	17.7	5.7	6.3	6.0	63.1	64.8	63.9	...	....	....	....
Maize meal	....	....	91.0	....	....	15.2	....	....	3.8	....	....	70.5	....	....	....	0.9
" " (*American*)	78.3	87.1	81.6	7.4	8.7	8.0	2.5	3.5	3.0	65.9	71.9	68.0	0.9	1.8	1.4	1.2
Rice " "	....	....	84.9	....	....	9.3	....	....	1.6	....	....	59.9	....	....	8.1	6.0
BYE PRODUCTS AND REFUSE.																
Rape cake	80.8	98.2	88.5	17.9	45.5	31.6	4.4	18.8	9.6	7.4	41.6	29.3	1.3	28.4	11.0	7.0
Extracted rape cake	85.5	96.1	91.5	21.8	36.8	33.1	1.8	6.8	3.0	26.9	38.8	34.1	11.1	20.3	13.4	7.9
Linseed cake	81.1	92.9	87.8	20.6	37.8	29.5	6.0	18.2	10.0	19.7	41.3	29.8	5.1	16.8	9.7	8.8
" " (*American*)	81.2	91.5	90.6	26.0	35.6	29.4	2.8	16.2	11.8	29.1	38.0	34.1	4.5	15.7	8.8	6.5
Extracted linseed cake	85.4	90.3	88.0	24.9	35.1	32.7	0.7	3.8	2 3	24.5	39.9	36.4	6.7	10.8	8.8	7.8
Poppy cake	84.7	95.7	88.5	24.4	37.8	31.9	3.9	17.0	8.2	8.5	29.6	25.9	10.3	22.8	11.5	11.0
Hemp "	83.5	92.2	88.8	25.1	34.4	30.2	4.3	10.2	6.7	12.2	30.3	21.2	16.0	25.9	22.9	7.8
Palm-nut cake	85.6	93.3	89.5	10.7	24.7	16.9	6.8	29.3	12.0	17.9	52.0	39.0	9.9	30.7	17.4	4.2
" " (*American*)	....	....	92.1	....	....	13.5	....	....	14.8	....	....	41.0	....	....	18.8	4.0
Extracted palm-nut meal	81.9	93.4	89.2	11.7	23.9	18.5	1.1	7.3	3.3	22.4	52.5	41.7	11.7	39.7	21.7	4.0
Cocoanut cake	87.9	94.0	90.6	16.3	37.2	20.6	6.9	22.7	13.2	28.4	47.4	37.4	7.5	21.1	14.2	5.2
Peanut cake (with shells)	88.2	92.2	90.2	27.0	34.9	31.0	5.9	11.2	8.9	11.9	28.5	20.7	19.1	28 0	22.7	6.9
" " (without shells)	87.5	92.2	91.3	43.2	47.5	45.3	1.7	9.9	8.5	17.2	33.6	26.5	4.8	8.2	5.4	5.6
Beechnut cake	79.3	90.0	83.9	15.8	24.0	18.2	0.4	11.7	8.3	21.6	36.3	28.3	20.8	26.2	23.9	5.2
" " (without shells)	....	....	87.5	..	....	37.1	....	....	7.5	....	....	29.7	....	....	5.5	7.7
Maize chits (*Maiskeime*)	....	....	88.1	....	....	12.4	....	....	17.4	....	....	46.0	....	....	6 8	5.5
"Hominy chops" (*American*)	86.5	88.4	87.5	9.5	9.8	9.7	8.6	9.3	8.9	62.0	62.6	62.3	3.2	4.8	4.0	2.6
Oil cake from maize chits	86.4	90.9	89.2	10.7	15.4	13.5	9.6	12.1	10.8	45.0	56.7	50.1	4.5	12.2	8.6	6.2

“*Corn feed.*” *Waste product from starch manufacture* (*American*)	....	....	37.7	....	....	5.6	....	....	1.3	....	....	28.9	....	....	1.6	0.3
“*Starch feed*” (*American*)	....	....	27.8	....	....	3.6	....	....	2.0	....	....	18.8	....	....	3.3	0.1
Cotton-seed cake	85.8	93.4	90.0	18.2	28.3	23.5	5.1	9.8	6.6	26.5	36.7	32.0	17.0	27.0	21.1	6.8
“ “ “ decorticated	85.7	92.3	90.0	19.7	43.8	40.9	5.4	19.7	16.4	10.5	27.4	15.8	5.4	11.4	9.0	7.9
“ “ “ *and meal* (*American*)	91.7	93.2	93.0	41.5	46.4	42.9	16.5	18.0	17.3	12.7	24.4	18.6	3.1	11.8	7.4	6.8
Olive cake	82.9	89.2	86.2	3.5	8.6	6.0	3.1	25.7	13.2	22.4	30.7	26.8	28.6	38.2	33.4	6.8
Wheat middlings	86.0	88.5	87.1	12.6	15.2	14.6	2.6	3.3	3.0	61.6	64.9	63.8	1.4	4.8	3.1	2.6
Wheat bran	83.5	92.4	87.0	10.1	27.0	14.5	1.7	6.6	3.5	28.5	61.5	53.6	4.1	34.6	9.4	6.0
Wheat bran and middlings (*American*)	86.7	89.5	88.5	10.1	14.2	12.7	2.1	4.9	3.5	55.6	70.9	61.8	3.5	10.5	6.7	3.8
Spelt bran	86.0	87.0	86.5	13.8	16.1	14.6	3.0	5.3	4.1	51.6	54.9	53.3	8.1	9.8	8.9	5.6
Rye bran	81.6	93.5	87.5	10.1	18.1	14.5	1.9	5.0	3.5	32.9	64.6	57.1	4.2	28.5	7.2	5.2
“ “ (*American*)	87.1	89.7	88.4	12.6	16.8	14 7	2.2	2.6	2.4	62.7	67.0	64.8	2.5	4.1	3.3	3.2
Bran of common millet	....	....	90.5	....	....	6.5	....	....	4.5	....	....	14.4	....	....	57.6	7.5
Barley bran	87.4	88.0	87.7	8.8	14.8	11.8	2.9	3.8	3.3	45.9	46.8	46.4	19.4	19.7	19.5	6.7
“ middlings	75.5	89.0	87.7	10.7	13.3	11.6	2.3	5.0	3 6	34.8	66.9	52.0	4.0	32.0	14.3	6.2
Oat bran	90.0	90.7	90.3	1.1	13.1	7.1	1.1	3.5	2.3	51.4	64.4	57.9	5.7	33.0	19.3	3.7
Rice middlings	84.3	92.3	90.0	3.8	15.6	10.7	0.4	15.9	9.9	35.9	75.9	47.7	1.5	36.2	11.1	10 6
“ husks	89.6	90.0	89.9	3.0	4.5	3.1	1.2	1.9	1.3	30.0	42.7	31.1	28.8	40.0	37.6	16.8
Green malt	....	....	52.0	6.0	6.5	6.3	....	....	1.5	37.4	38.0	37.7	4.3	5.2	4.7	1 8
Dry “	90.0	95.8	92.5	8 8	10.0	9.4	2.2	2.5	2.35	65.7	73.7	69.7	8.0	9.5	8.7	2.3
Malt sprouts	79.5	96.8	89.9	13.7	32.4	24.2	0.7	4.0	2.1	18.5	48.2	42.1	5.0	32.1	14.3	7.2
“ “ (*American*)	....	....	88.5	....	....	25.9	....	....	1 1	....	....	45.5	....	....	9.3	6.7
Brewers' grains	17.0	30.0	22.3	2.9	6.3	4.6	1.1	2.5	1.6	3.2	14.8	9.9	2.8	9.5	5.0	1.2
“ “ (*American*)	21.5	24.8	23.1	4.7	5.9	5.3	....	....	....	12.6*	14.7*	13.6*	3.1	3.9	3.5	0.7
“ “ dried	....	....	90.3	....	....	23.1	....	....	7.8	....	....	44.6	....	....	10.4	4.4
Steamed and fermented potatoes	25.8	29.2	27.3	2.7	3.5	3.1	0.23	0.5	0.4	19.2	22.8	21.0	0.7	1.8	1.2	1.6
Potato “slump”	3.8	8.7	7.7	0.8	1.9	1.4	0.1	0.23	0.2	1.1	4.9	4.6	0.5	1.4	0.9	0.6
Distillers' grains, rye	4.3	12.3	9.3	1.0	2.1	1.9	0.25	0.9	0.4	2.6	7.0	6.3	0.3	1.6	1.2	0.5
“ “ maize	7.8	11.0	9.4	1.9	2.0	2.0	0.8	1.2	1.0	3.8	6.0	4.9	0.6	1.3	1.0	0.5
Sugar beet “slump”	...	....	9.0	....	....	0.9	....	....	0.1	....	....	6.2	....	....	1.2	0.6
Beet molasses “slump”	6.4	9.8	8.0	1.2	3.0	1.8	....	....	....	2.7	5.8	4.6	....	....	....	1.6
Potato fibre (residue from potato starch manufacture)	10.6	17.6	15.0	0.6	1.1	0.8	0.07	0.1	0.09	6.3	15.0	11.7	1.3	3.2	2.0	0.4
Same, air dry	76.9	88.0	81.9	2.6	10.2	7.2	0.6	3.5	0.8	52.3	76.4	63.7	0.5	17.8	6.5	3.7
Residue from manufacture of wheat starch	21.5	32.5	26.0	2.3	6.6	4.4	1.55	2.6	2.2	13.1	18.0	15.4	2.7	4.6	3.4	0.6
Sugar beet molasses	75.5	89.2	81.4	4.0	10·5	8.1	....	....	....	58.6	66.8	63.0	....	....	....	10.3

* Including fat.

TABLE I.—(*Continued.*)

	TOTAL DRY MATTER.			PROTEIN			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.			ASH.
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	
BYE PRODUCTS AND REFUSE.																
Sugar beet cake	23.0	35.5	29.7	1.0	3.0	1.9	0.1	0.7	0.2	8.3	19.5	18.3	4.1	8.6	6.3	3.0
" " residue from centrifugal machines	15.0	18.0	16.0	0.8	1.0	0.9	....	....	0.1	4.3	12.4	10.7	2.6	3.9	3.1	1.2
" " residue from diffusion process, fresh	5.0	9.2	6.9	0.4	0.8	0.6	0.03	0.1	0.08	3.2	5.4	4.0	1.2	2.5	1.5	0.7
Same, fermented	8.0	10.0	8.3	0.7	0.9	0.8	....	....	0.03	....	....	4.3	....	....	1.7	1.4
" pressed and fermented	8.3	13.9	11.0	0.6	1.5	0.9	0.03	0.6	0.1	4.7	8.4	6.1	2.2	3.2	2.9	1.0
Fresh cow's milk	9.5	15.5	12.0	2.0	6.8	3.2	1.5	6.0	3.6	2.9	8.3	4.5	....	....	....	0.7
" goat's "	10.7	17.7	13.1	2.4	6.6	3.7	2.5	9.4	4.1	3.0	5.7	4.4	....	....	....	0.9
Skimmed "	7.6	11.5	10.0	2.5	4.9	3.5	0.3	1.4	0.7	3.1	6.1	5.0	....	....	....	0.8
Cream	28.2	47.5	36.9	2.6	6.0	5.1	16.9	41.2	29.0	2.1	3.9	2.4	....	....	....	0.4
Buttermilk	9.2	10.3	9.9	2.5	3.8	3.0	0.2	1.5	1.0	5.0	6.0	5.4	....	....	...	0.5
Whey	5.4	8.6	7.2	0.5	1.35	1.0	0.1	1.1	0.6	4.0	6.1	5.0	....	....	....	0.6
Flesh meal	86.4	90.9	88.5	46.0	74.7	72.8	1.2	13.2	12.0	....	....	....	....	....	....	3.7
Norwegian fish guano	....	....	87.4	....	....	49.0	....	....	1.8	....	....	....	....	....	....	36.6
American " " *	76.1	91.5	84.0	21.7	57.9	48.8	7.3	18.6	8.1	....	....	....	....	....	....	....
" " " Goodale's process*	88.6	89.6	89.3	....	....	64.0	1.3	4.1	2.3	....	....	....	....	....	....	....
Dried blood (Wolff)	....	....	88.0	....	....	80.8	....	...	0.5	....	....	2.6	....	....	....	4.1
" " (*American*) †	78.0	90.1	85.1	44.6	73.6	58.9	....	....	....	....	....	....	....	....	....	....

* From analyses in Reports of Connecticut Agricultural Experiment Station, 1877, 1878, and 1879.
† Average of analyses in Report Connecticut Agricultural Experiment Station, 1879.

TABLE II.—DIGESTIBILITY OF FEEDING-STUFFS.*

	PROTEIN.			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.		
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.
GREEN FODDER.												
Pasture grass	70.6	79.3	75	63.4	68.1	66	74.5	84.4	79	70.3	75.2	73
Meadow grasses	69.0	71.7	70	60.4	68.1	65	74.7	84.4	79	65.4	72.8	69
Pasture clover	77.7	78.7	78	63.3	65.1	64	78.0	78.5	78	66.9	67.4	67
Red clover, just before blossoming	70.5	74.3	73	57.0	65.2	62	69.6	83.2	76	50.1	60.4	55
" beginning to blossom	71.7	76.3	74	66.1	75.3	71	73.0	80.1	77	52.2	59.2	56
" in full blossom	64.7	70.2	67	58.6	65.4	63	68.3	72.6	70	46.4	50.1	48
" nearly out of blossom	56.4	60.8	59	42.2	46.7	45	70.3	71.0	71	38.3	39.3	39
The digestibility of red clover may also serve as the basis for estimating that of other kinds of clover.												
Lucerne (before and in the beginning of flowering)	78.2	83.2	81	37.0	53.6	45	61.1	76.9	72	31.6	46.8	41
Esparsette	71.7	73.3	73	64.1	69.2	67	76.5	80.0	78	42.1	42.3	42
Vetches †	73.0	80.0	76	50.0	65.8	60	63.3	67.3	65	51.2	58.3	54
Lupines †	73.0	75.7	74	15.5	45.3	30	57.3	65.9	62	67.1	79.8	73
Potato tops	....	....	42	....	....	24	....	....	60	....	....	36
Maize fodder (very good)	....	....	73	....	....	75	....	....	67	....	....	72
Sorghum	....	....	62	....	....	85	....	....	78	....	....	60
Poplar leaves	....	....	56	....	....	79	....	....	65	....	....	35

* The numbers of the table denote that of the total quantity of the given ingredient contained in the feeding-stuff, the percentage expressed by the number given is digestible; *e. g.*, on the average, 75 per cent of the amount of protein contained in pasture grass is digestible. Those feeding-stuffs whose digestibility has not been experimented on, and whose coefficients can therefore be obtained only by comparison, are distinguished by smaller type.

† The coefficients for vetches and lupines were obtained in experiments on very good hay of these plants, but may also serve as a basis for estimating the digestibility of green fodder.

TABLE II.—(*Continued.*)

	PROTEIN.			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.		
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.
GREEN FODDER.												
Serradella, beans, peas, spurry, white mustard, green rape, cabbage, turnip leaves, parsnip leaves.	....	....	71	....	....	60	....	....	100*	....	....	....
Fodder rye, fodder oats, beet leaves, carrot leaves, buckwheat, artichoke tops	....	....	57	....	....	46	....	....	100*	....	....	....
HAY.												
Meadow hay (experiments on ruminants)	38.9	71.0	57	8.5	69.7	46	48.0	78.8	63	44.6	72.4	58
" " " " horse	54.1	68.8	62	13.4	42.6	20	48.5	65.8	56	33.1	57.0	42
" " (Wolff's classification) Very good	54.0	79.0	64	31.0	68.0	48	61.0	84.0	67	54.0	75.0	64
Medium	42.0	63.0	56	10.0	65.0	48	49.0	71.0	63	46.0	71.0	57
Inferior	42.0	57.0	52	10.0	61.0	49	49.0	71.0	61	46.0	68.0	57
Rowen	53.0	68.0	61	27.0	57.4	46	56.7	75.0	66	54.3	74.9	63
Clover hay	43.0	73.3	60	33.0	75.3	59	62.5	80.1	69	38.0	59.2	47
" " (Wolff's classification) Excellent	....	....	70	....	....	64	....	....	73	....	....	53
Very good	....	....	63	....	....	60	....	....	71	....	....	49
Average	....	....	55	....	....	56	....	....	69	....	....	44
Lucerne hay (very carefully dried. Compare pp. 260–262)	72.1	83.0	77	29.7	51.0	39	52.6	72.0	65	33.1	45.7	40
" " (experiments on horse)	73.3	77.0	74	....	....	6	69.5	71.8	70	33.0	42.9	39
Esparsette hay (very carefully dried)	69.7	70.2	70	65.1	67.4	66	73.6	75.0	74	33.3	39.4	36
Hay of fodder vetches	73.0	80.0	76	50.0	65.8	60	63.3	67.3	65	51.2	58.3	54
Lupine hay	73.0	75.7	74	15.5	45.3	30	57.3	65.9	62	67.1	79.8	73

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* The number 100 for the nitrogen-free extract indicates simply that the sum of the digestible extract and crude fibre is equal to the total amount of nitrogen-free extract.

Sour hay (Ensilage) of beet leaves..........	....	....	65	....	....	60	....	....	54	....	....	54
The digestibility of clover hay may serve as a basis for estimating that of the hay of other legumes, and the digestibility of meadow hay for estimating that of hay from the cultivated grasses.												
STRAW.												
Wheat straw..............................	....	....	26	....	....	27	....	....	40	....	....	52
" " (experiments on horse)........	....	....	?	....	....	?	....	....	17	....	....	27
Rye "	2.6	82.6	25	21.2	40.9	32	28.5	51.8	36	46.8	72.9	56
Oat "	14.4	50.0	38	14.0	51.0	30	33.2	47.0	42	53.0	67.0	61
Barley " (inferior)......................	12.8	16.8	15	32.4	42.6	38	50.7	51.3	51	49.1	55.6	52
Bean "	49.0	55.0	51	50.0	60.0	55	57.0	64.0	61	33.0	39.0	36
Pea " (very good)..................	60.3	60.6	60.5	41.6	50.1	46	64.0	64.8	64	47.2	55.9	52
Lupine "	35.4	39.7	37	25.4	35.0	30	64.5	65.4	65	49.2	52.0	51
The coefficients of wheat straw may also be applied to spelt straw and stover, those of oat straw to barley straw, those of bean straw to vetch straw, and those of pea straw to lentil straw.												
Rape straw....................................	....	....	40	....	....	30	....	....	100*	....	....	....
CHAFF AND HULLS.												
No determinations of the digestibility of these feeding-stuffs have been made. In view of their somewhat higher percentage of crude protein as compared with the corresponding straw, the maximum coefficients for straw may probably be assumed as representing approximately the average digestibility of chaff and hulls.												
TUBERS AND ROOTS.												
The digestibility of these feeding stuffs is so great that they may, for practical purposes, be assumed to be completely digestible. The large proportion of non-protein which they contain must be remembered in compounding rations.												
GRAINS.												
Oats (experiments on ruminants)...........	58.0	81.3	74	68.4	99.0	82	65.0	79.7	73	5.5	32.1	21

* See note on opposite page.

TABLE II.—(*Continued.*)

	* PROTEIN.			FAT.			NITROGEN-FREE EXTRACT.			CRUDE FIBRE.		
	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.	Minim.	Maxim.	Average.
GRAINS.												
Oats (experiments on horse)	79.7	94.0	87	70.7	85.5	78	72.9	84.0	77	0	49.0	26
Barley " " ruminants)	....	....	77	....	....	100	....	....	87	....	....	20
" " " swine)	74.6	80.7	78	58.2	77.3	69	89.3	91.3	90	14.4	27.4	20
Maize " " "	83.9	88.1	85	74.4	78.5	76	92.5	93.3	94	17.0	57.4	34
" " sheep)	77.5	79.5	79	83.1	86.0	85	90.2	92.4	91	58.0	65.8	62
" " " horse)	....	....	78	....	....	63	....	....	94	....	....	100
Beans " " ruminants)	80.6	100.0	90	86.9	100.0	97	90.7	98.7	94	25.1	100.0	63
" " " horse)	83.7	90.0	86	....	....	8	91.8	95.5	93	46.8	96.2	69
Peas " " swine)	84.4	91.5	88	45.0	69.0	58	94.7	98.6	97	55.1	88.5	74
Lupines " " sheep)	95.5	97.6	97	....	....	100	77.0	100.0	90	....	....	...
BYE PRODUCTS AND REFUSE.												
Rape cake (experiments on cows and oxen)	81.3	92.4	85.4	79.7	93.6	88	70.2	84.9	78	0	34.3	11
" " " " sheep)	65.3	83.9	75.9	59.8	77.2	69	66.0	85.4	78	0	5.5	3
Linseed cake " " oxen)	80.2	89.9	87	86.7	93.9	91	85.0	96.3	91	....	54.5	26
" " " " goats and sheep)	80.0	87.4	83	86.5	92.5	90	60.0	78.7	71	29.7	92.9	62
Palm-nut cake and meal (experiments on ruminants)	95.0	100.0	98	95.0	100.0	98	92.0	96.0	94	72.2	92.0	82
Cocoanut cake (experiments on swine)	72.7	74.2	74	81.8	84.6	83	87.3	91.2	89	54.7	66.0	60
Cotton-seed cake (experiments on sheep)	69.4	78.0	74	83.3	100.0	91	37.6	54.7	46	7.1	36.2	23
Wheat bran, fed dry (experiments on oxen)	82.9	93.5	88	77.6	81.6	80	77.7	81.2	80	16.9	32.2	20
" " variously prepared (experiments on oxen)	61.6	81.0	70	68.8	89.9	81	69.7	82.4	75	3.5	21.5	13
" " (experiments on sheep)	....	....	75	....	....	50	....	....	70	....	....	37

Spelt bran (experiments on sheep)	65.5	85.2	73	81.3	93.8	88	81.3	100.0	91	1.21	100.0	?
Rye " " " swine)	65.8	66.2	66	57.4	57.6	57.5	74.2	74.7	74.5	6.5	10.5	9
Brewers' grains	....	....	85	....	....	80	....	....	100*	....	....	....
Malt sprouts	....	....	80	....	....	80	....	....	100*	....	....	....
Sour milk (experiments on swine)	....	....	96	....	....	95	....	....	99	....	....	....
Flesh meal " " ruminants)	....	....	95	....	....	98	....	....	....	....	....	....
" " " " swine)	95.1	98.9	97	82.3	90.7	87	....	....	....	....	....	....
Fish guano " " ruminants)	....	....	90	....	....	76	....	....	....	....	....	....
Dried blood " " "	....	....	62	....	....	100	....	....	100	....	....	....
" " " " swine)	....	....	72	....	....	....	....	....	92	....	....	....

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* See note, p. 488.

TABLE III.—FEEDING STANDARDS.

A.—PER DAY AND PER 1,000 LBS. LIVE-WEIGHT.

	Total organic substance.	Nutritive (Digestible) Substances.			Total nutritive substance.	Nutritive ratio.
		Albuminoids.	Carbhydrates.	Fat.		
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
1. Oxen at rest in stall.........	17.5	0.7	8.0	0.15	8.85	1 : 12.0
2. Wool sheep, coarser breeds...	20.0	1.2	10.3	0.20	11.70	1 : 9.0
“ “ finer breeds.....	22.5	1.5	11.4	0.25	13.15	1 : 8.0
3. Oxen moderately worked....	24.0	1.6	11.3	0.30	13.20	1 : 7.5
“ heavily worked........	26.0	2.4	13.2	0.50	16.10	1 : 6.0
4. Horses moderately worked...	22.5	1.8	11.2	0.60	13.60	1 : 7.0
“ heavily worked......	25.5	2.8	13.4	0 80	17.00	1 : 5.5
5. Milk cows...................	24.0	2.5	12.5	0.40	15.40	1 : 5.4
6. Fattening oxen, 1st period...	27.0	2.5	15.0	0.50	18.00	1 : 6.5
“ “ 2d “ ...	26.0	3.0	14.8	0.70	18.50	1 : 5.5
“ “ 3d “ ...	25.0	2.7	14.8	0.60	18.10	1 : 6.0
7. Fattening sheep, 1st period..	26.0	3.0	15.2	0.50	18.70	1 : 5.5
“ “ 2d “ ..	25.0	3.5	14.4	0.60	18.50	1 : 4.5
8. Fattening swine, 1st period..	36.0	5.0	27.5		32.50	1 : 5.5
“ “ 2d “ ..	31.0	4.0	24.0		28.00	1 : 6.0
“ “ 3d “ ..	23.5	2.7	17.5		20.20	1 : 6.5
9. Growing cattle:						
Age, months. Average live-weight, per head.						
2–3 .... 150 lbs.*......	22.0	4.0	13.8	2.0	19.8	1 : 4.7
3–6 .... 300 “	23.4	3 2	13.5	1.0	17.7	1 : 5.0
6–12 .... 500 “	24.0	2.5	13.5	0 6	16.6	1 : 6.0
12–18 .... 700 “	24.0	2.0	13 0	0 4	15 4	1 : 7.0
18–24 .... 850 “	24.0	1.6	12.0	0.3	13.9	1 : 8.0
10. Growing sheep:						
5–6 .... 56 lbs.*......	28.0	3.2	15.6	0.8	19.6	1 : 5.5
6–8 .... 67 “	25.0	2.7	13 3	0.6	16.6	1 : 5.5
8–11 .... 75 “	23.0	2 1	11.4	0.5	14.0	1 : 6.0
11–15 .... 82 “	22.5	1.7	10.9	0.4	13.0	1 : 7.0
15–20 .... 85 “	22.0	1.4	10.4	0.3	12.1	1 : 8.0
11. Growing fat pigs:						
2–3 .... 50 lbs.*......	42.0	7.5	30.0		37.5	1 : 4.0
3–5 .... 100 “	34.0	5.0	25.0		30.0	1 : 5.0
5–6 .... 125 “	31.5	4.3	23.7		28.0	1 : 5.5
6–8 .... 170 “	27.0	3.4	20 4		23.8	1 : 6.0
8–12 .... 250 “	21.0	2.5	16.2		18.7	1 : 6.5

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* See note on opposite page.

TABLE III.—*Continued.*

B.—PER DAY AND PER HEAD.

	Total organic substance.	NUTRITIVE (DIGESTIBLE) SUBSTANCES.			Total nutritive substance.	Nutritive ratio.
		Albuminoids.	Carbhydrates.	Fat.		
Growing cattle:	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
Age, months. Average live-weight, per head.						
2–3 .... 150 lbs.*	3.3	0.6	2.1	0.30	3.00	1 : 4.7
3–6 .... 300 "	7.0	1.0	4.1	0.30	5.40	1 : 5.0
6–12 .... 500 "	12.0	1.3	6.8	0.30	8.40	1 : 6.0
12–18 .... 700 "	16.8	1.4	9.1	0.28	10.78	1 : 7.0
18–24 .... 850 "	20.4	1.4	10.3	0.26	11.96	1 : 8.0
Growing sheep:						
5–6 .... 56 lbs.*	1.6	0.18	0.87	0.045	1.095	1 : 5.5
6–8 .... 67 "	1.7	0.17	0.85	0.040	1.060	1 : 5.5
8–11 .... 75 "	1.7	0.16	0.85	0.037	1.047	1 : 6.0
11–15 .... 82 "	1.8	0.14	0.89	0.032	1.062	1 : 7.0
15–20 .... 85 "	1.9	0.12	0.88	0.025	1.047	1 : 8.0
Growing fat swine:						
2–3 .... 50 lbs.*	2.1	0.38	1.50		1.88	1 : 4.0
3–5 .... 100 "	3.4	0.50	2.50		3.00	1 : 5.0
5–6 .... 125 "	3.9	0.54	2.96		3.50	1 : 5.5
6–8 .... 170 "	4.6	0.58	3.47		4.05	1 : 6.0
8–12 .... 250 "	5.2	0.62	4.05		4.67	1 : 6.5

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* The German pound is equal to $1^{1}/_{10}$ lb. avoirdupois. The above weights are therefore to be increased $^{1}/_{10}$ to represent our weights. For practical purposes, however, this reduction will be in most cases unnecessary, as the weights are but relative and approximate. The quantities of nutrients calculated per 1,000 pounds live-weight, of course, need no reduction, being simply relative, and the same is true to a certain extent of the quantities per head.

TABLE IV.—PROPORTIONS OF THE VARIOUS PARTS OF CATTLE, SHEEP, AND SWINE.

	Ox.			Fat calf.	Sheep.					Swine.	
	Well-fed.	Half fat.	Fat.		Lean.	Well-fed.	Half fat.	Fat.	Very fat.	Well-fed.	Fat.
	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
Contents of stomach and intestines	18.0	15.0	12.0	7.0	16.0	15.0	14.0	12.0	10.0	7.0	5.0
Blood	4.7	4.2	3.9	4.8	3.9	3.9	3.6	3.2	3.2	7.3	3.6
Skin and horns	8.4	7.4	6.0	6.8	9.6	9.3	8.0	7.2	6.5	....	....
Legs to gambrel joint	1.9	1.7	1.6	1.9							
Washed wool	....	....	....	....	5.0	4.7	4.3	4.0	3.6	....	....
Wool-dirt	....	....	....	....	4.8	4.5	4.0	3.6	3.2	....	....
Head	2.8	2.7	2.6	4.8	4.6	4.3	3.7	3.2	2.8	.... 0.5	....
Tongue and gullet	0.6	0.6	0.5								0.4
Heart	0.4	0.5	0.5	0.6	0.4	0.3	0.4	0.3	0.2	0.5	0.3
Lungs and wind-pipe	0.7	0.7	0.6	1.2	1.5	1.5	1.2	1.0	1.0	1.4	0.9
Liver and gall-bladder	1.5	1.3	1.3	1.6	1.4	1.3	1.3	1.3	1.0	2.6	1.7
Diaphragm	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.2	0.2	....	....
Spleen	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.1	0.2	0.2
Stomach, without contents	4.5	3.0	2.7	1.2	2.4	2.3	2.3	2.0	1.5	1.2	0.7
Intestines " "	2.0	1.5	1.4	2.4	2.3	2.2	1.9	1.7	1.3	3.9	2.2
Fat of omentum and intestines	2.3	2.9	4.5	2.4	3.0	4.1	4.9	6.8	8.0	1.7	2.5
Four quarters, including kidneys and kidney-fat	47.4	55.7	60.3	60.0	43.3	45.3	49.4	52.8	57.1	72.8	82.1
Loss	4.1	2.1	1.4	4.6	1.3	0.8	0.5	0.6	0.3	0.9	0.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

SUMMARY.

Blood	4.7	4.2	3.9	4.8	3.9	3.9	3.6	3.2	3.2	7.3	3.0

Skin, head, legs, and tongue	13.7	12.4	10.7	13.5	24.0	22.8	20.0	18.0	16.1	....	....
Entrails	9.8	7.7	7.2	7.7	8.5	8.1	7.7	6.6	5.3	9.8	6.0
Flesh and fat	49.7	58.6	64.8	62.4	46.3	49.4	54.3	59.6	65.1	74.5	84.6
Contents of stomach and intestines	18.0	15.0	12.0	7.0	16.0	15.0	14.0	12.0	10.0	7.0	5.0
CONSTITUENTS OF CARCASS. (*Dressed weight, including fat of omentum, etc.*)											
Flesh, without fat and bones	36.0	38.0	35.0	43.0	33.2	33.5	33.1	29.0	27.0	46.4	40.0
Bones	7.4	7.3	7.1	9.3	7.1	6.6	5.9	5.5	5.2	8.0	5.8
Fat in flesh	2.0	7.9	14.7	5.5	2.0	3.3	8.0	14.7	20.5	16.5	32.4
Fat on kidneys	2.0	2.5	3.5	2.2	1.0	1.9	2.4	3.6	4.4	1.9	3.9
" omentum and intestines	2.3	2.9	4.5	2.4	3.0	4.1	4.9	6.8	8.0	1.7	2.5
Total	49.7	58.6	64.8	62.4	46.3	49.4	54.3	59.6	65.1	74.5	84.6
FLESH OF CARCASS WITHOUT FAT AND BONES.											
Dry matter	8.0	8.4	7.5	8.8	6.8	6.7	6.3	5.4	5.1	8.1	7.3
Water	28.0	29.6	27.5	34.2	26.4	26.8	26.8	23.6	21.9	38.3	32.7
Total	36.0	38.0	35.0	43.0	33.2	33.5	33.1	29.0	27.0	46.4	40.0
IN 100 PARTS OF FLESH WITHOUT BONES. (*Butchers' meat.*)											
Fat	5.3	17.2	29.4	11.3	5.7	9.0	19.5	33.6	43.2	26.2	45.5
Muscle substance	19.8	17.5	14.5	17.0	18.0	17.1	14.5	11.7	10.2	12.3	9.7
Ash	1.2	0.9	0.8	1.1	1.3	1.1	0.8	0.7	0.6	0.6	0.4
Water	73.7	64.4	55.3	70.6	75.0	72.8	65.2	54.0	46.0	60.9	44.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
PERCENTAGE COMPOSITION OF LIVE ANIMAL.											
Fat	7.1	14.9	26.8	13.1	8.6	13.2	18.3	28.1	37.2	22.5	40.2
Protein	15.8	15.5	13.7	15.3	15.4	14.8	13.8	12.2	11.0	13.9	11.0
Ash	4.8	4.4	3.9	4.5	3.4	3.3	3.2	2.9	2.8	2.7	1.8

TABLE IV.—*Continued.*

	Ox.				Sheep.					Swine.	
	Well-fed.	Half fat.	Fat.	Fat calf.	Lean.	Well-fed.	Half fat.	Fat.	Very fat.	Well-fed.	Fat.
PERCENTAGE COMPOSITION OF LIVE ANIMAL.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
Water	54.3	50.2	43.6	60.1	56.6	53.7	50.7	44.8	39.0	53.9	42.0
Contents of stomach and intestines	18.0	15.0	12.0	7.0	16.0	15.0	14.0	12.0	10.0	7.0	5.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
THE SAME, LESS CONTENTS OF STOMACH AND INTESTINES.											
Fat	8.7	17.5	30.5	14.1	10.2	15.5	21.3	31.9	41.4	24.2	42.3
Protein	19.2	18.3	15.6	16.5	18.3	17.4	16.0	13.9	12.2	15.0	11.9
Ash	5.9	5.2	4.4	4.8	4.0	3.9	3.8	3.3	3.1	2.9	1.9
Water	66.2	59.0	49.5	64.6	67.5	63.2	58.9	50.9	43.3	57.9	43.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MINERAL MATTERS IN 100 PARTS OF LIVE ANIMAL.											
Phosphoric acid	1.92	1.76	1.56	1.64	1.33	1.29	1.25	1.13	1.09	1.10	0.73
Lime	2.14	1.96	1.74	1.93	1.40	1.35	1.31	1.19	1.15	1.15	0.77
Magnesia	0.06	0.06	0.05	0.06	0.05	0.04	0.04	0.04	0.04	0.05	0.03
Potash	0.18	0.16	0.14	0.29	0.16	0.16	0.15	0.14	0.13	0.15	0.10
Soda	0.14	0.13	0.12	0.07	0.15	0.15	0.14	0.13	0.12	0.10	0.07
Silica	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	....	....
Sulphuric acid, chlorine, and carbonic acid	0.34	0.32	0.28	0.50	0.29	0.29	0.29	0.25	0.25	0.15	0.10
Total	4.80	4.40	3.90	4.50	3.40	3.30	3.20	2.90	2.80	2.70	1.80

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